Section E : Radioactivity

II Atomic Model

(Revision Course)

PHYSICS

CW Sham

& His Team

2015 DSE 超過47%^學生考獲Level 5或以上
(全港比率只有27.1%) ^截至2015年8月20日，透過遵理網上成績登記系統及電話調查紀錄。

College BEACON 遵理學校

Diploma of Secondary Education

Section E : Radioactivity

II Atomic Model

(Revision Course)

C.W.Sham

College BEACON 遵理學校

問沈Sir 功課

Telephone : 96221786

Facebook : cwsham901

WhatsApp : +852 96221786

Section E : Radioactivity II – Atomic Model

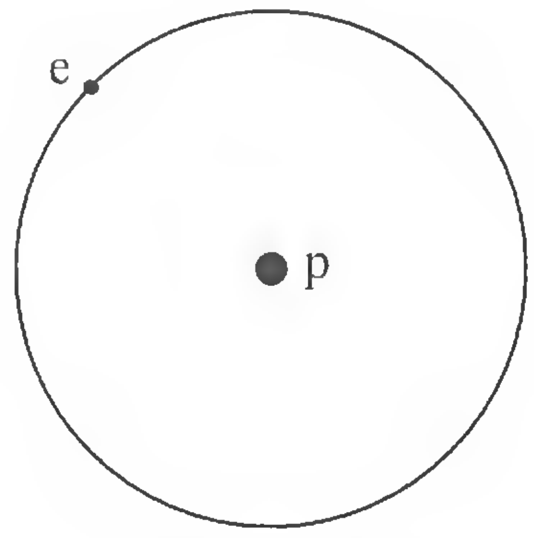
C.W.Sham

Contents

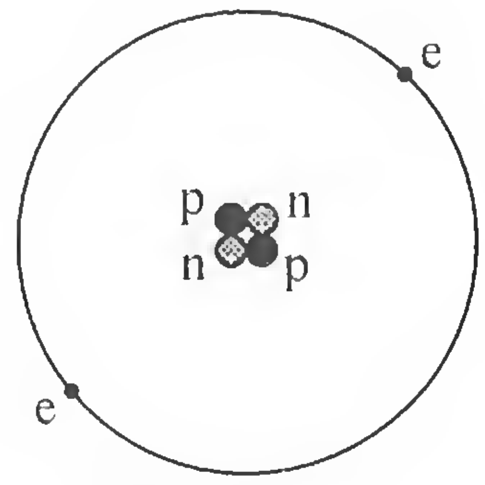
1. The atom of an element（元素的原子）

(i) Atomic number and mass number（原子序數及質量數）

✧ **An atom consists of a nucleus（核）and the surrounding electrons (e)（電子).**



Hydrogen atom



Helium atom

✧ **The nucleus contains protons (p)（質子）and neutrons (n)（中子).**

✧ **Notation of an atom :** ${}^{A}_{Z}X$

Z : atomic number（原子序數）

A : mass number（質量數）

✧ **Atomic number = Number of proton**

✧ **Mass number = total number of protons and neutrons**

i.e. $A = Z + N$, where N is the number of neutrons

✧ **Both proton and neutron belong to nucleon（核子).**

✧ **An atom must be neutral.**

∴ number of electrons in an atom = number of protons in an atom

✧ **A nuclide（核素）is a type of nucleus with the same number of protons and neutrons.**

e.g. ${}^{16}_{8}O$, ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$ are different nuclides

(ii) Notation of some elementary particles（基本粒子的符號）

① **Proton（質子）:** ${}^{1}_{1}p$ $m_p \neq m_n$

② **Neutron（中子）:** ${}^{1}_{0}n$

③ **Electron（電子）:** ${}^{0}_{-1}e$ $m_e \neq 0$

④ **Alpha particle (α) :** ${}^{4}_{2}\alpha$ **OR** ${}^{4}_{2}He$

⑤ **Beta particle (β) :** ${}^{0}_{-1}\beta$ **OR** ${}^{0}_{-1}e$

⑥ **Gamma radiation (γ) :** γ

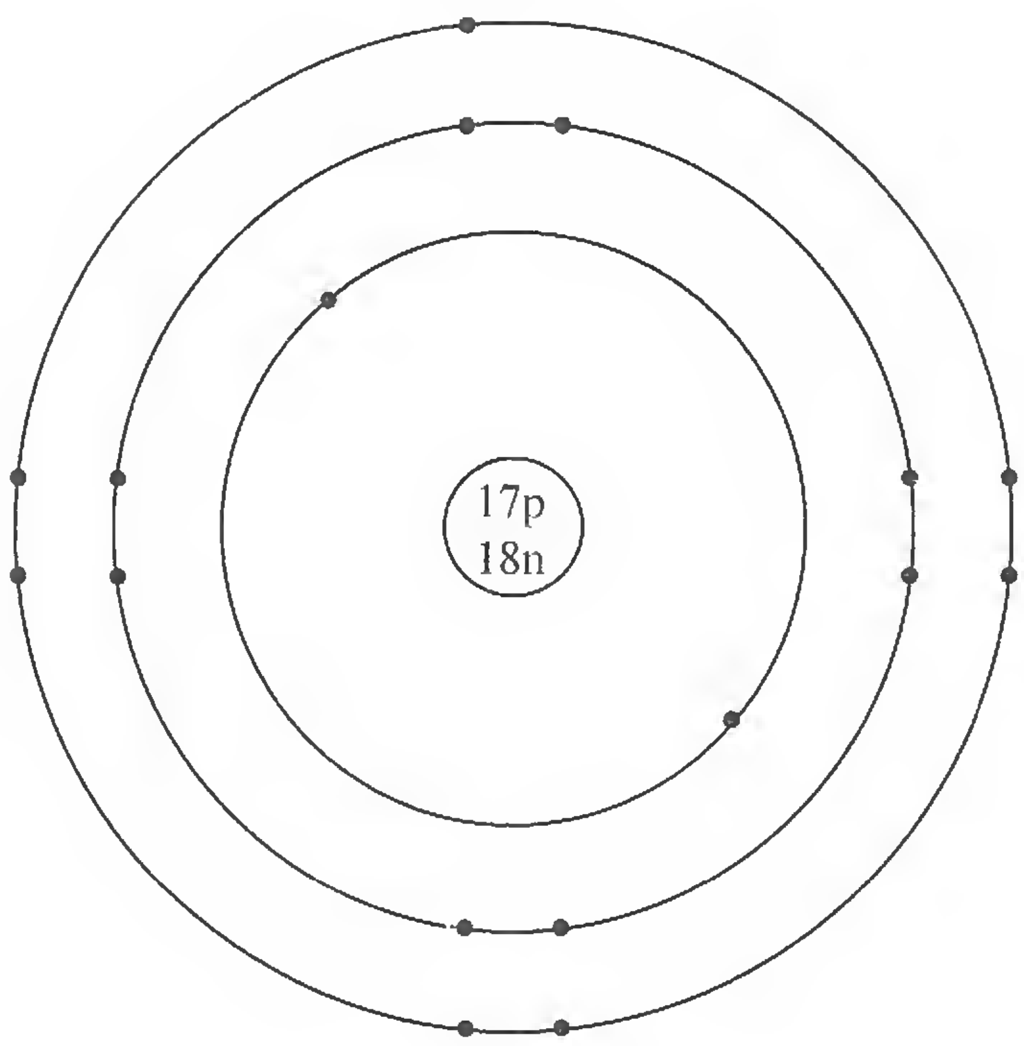
(iii) Isotopes（同位素）

✧ **Isotopes are the same element（元素）with the same number of protons but different number of neutrons.**

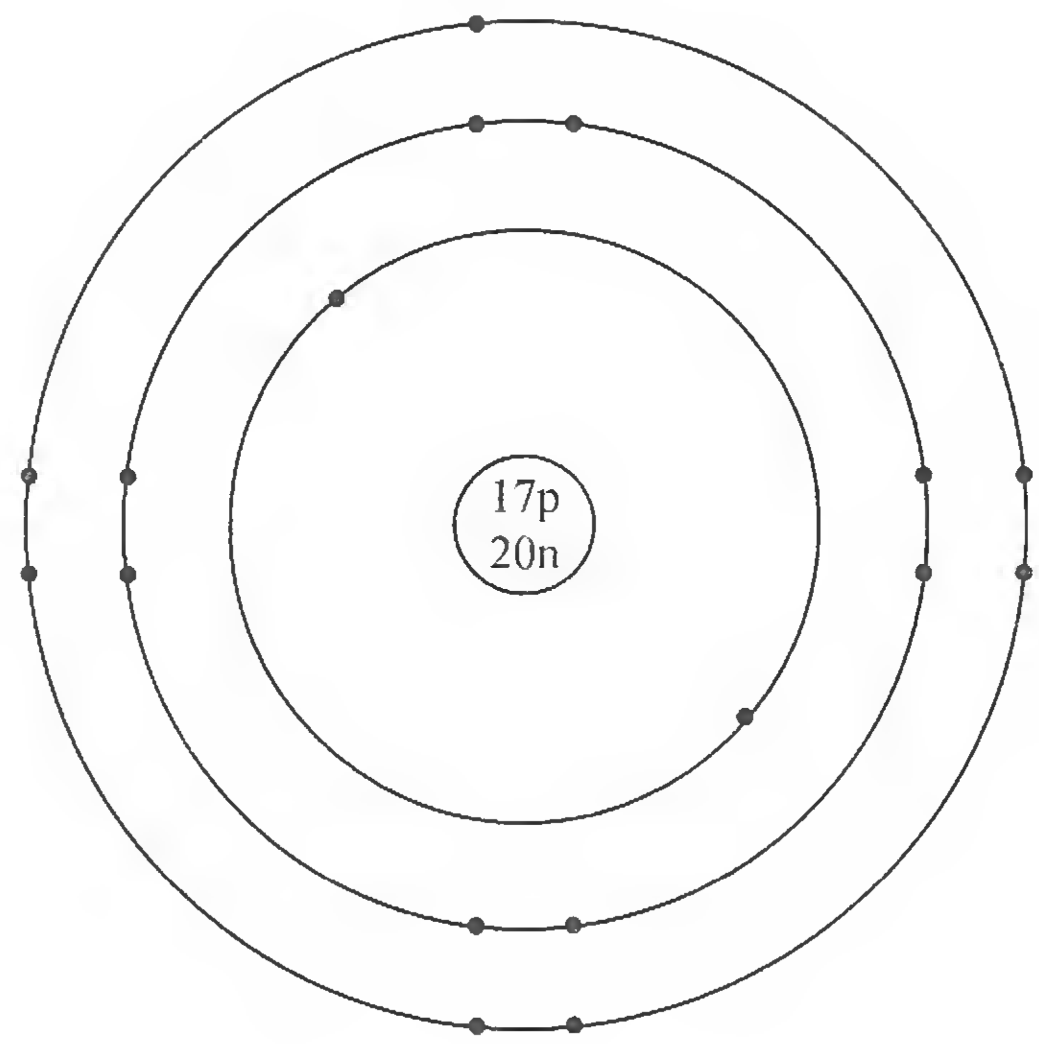
✧ **Isotopes have the same atomic number Z but different mass number A.**

✧ **Isotopes have the same chemical properties but different physical properties.**

$^{35}_{17}Cl$



$^{37}_{17}Cl$



✧ **An isotope which is radioactive is called radioisotope（放射性同位素）.**

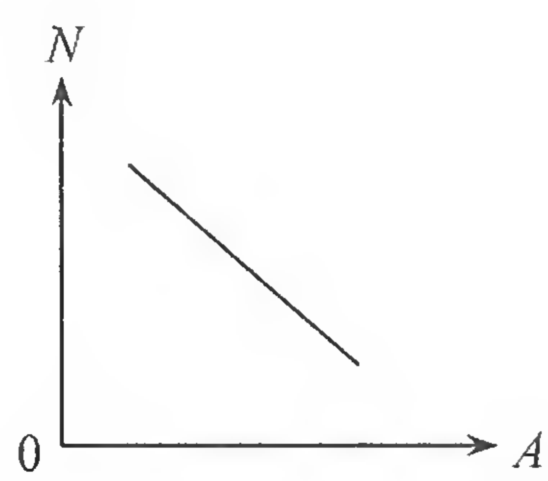
✧ **An element may have stable isotope and radioisotope**

e.g. carbon-12 is a stable nuclide ; carbon-14 is a radioactive nuclide.

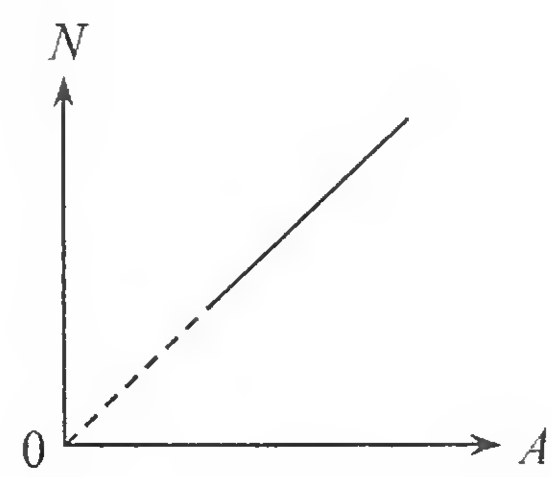
Example : Isotopes of an element have different mass number A and neutron number N. Which of the following $N - A$ plots correctly shows the relationship of N and A for any given element ?
{2012}

$A = Z + N$ $N = 1 \cdot A - Z$ $y = mx + c$

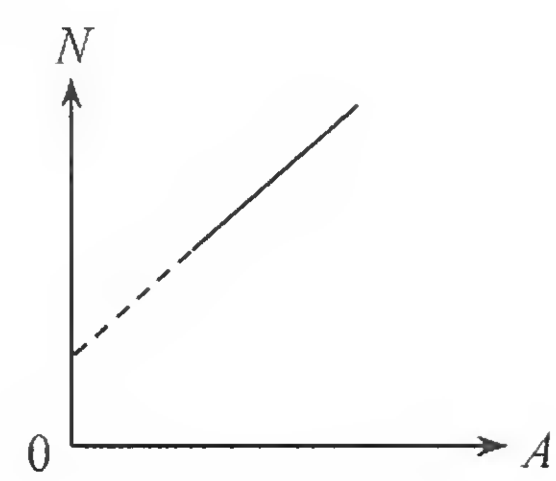
A.



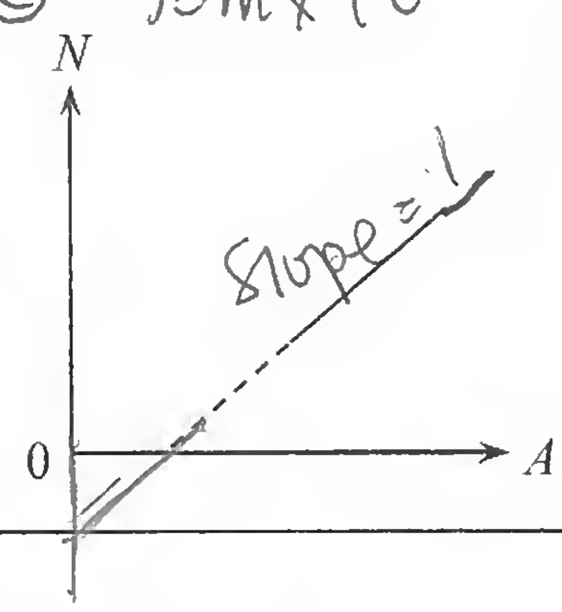
B.



C.



D.



Example : The atomic number of Tin is 50 and its mass number is 112. Which of the following is an isotope of Tin ?
(1988) A. $^{112}_{51}X$ B. $^{114}_{50}X$ C. $^{112}_{49}X$ D. $^{112}_{62}X$

Example : Isotopes of an element have different chemical properties. F
(1991)

Isotopes of an element have different number of neutrons in their nuclei. T

(iv) Number of mole (摩爾數量)

✧ **Consider the following quantities :**

- ✻ N is the number of atoms
- ✻ N_A is the Avogadro Constant (阿佛加德羅常數) $\{N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}\}$
- ✻ M is the total mass of the substance
- ✻ $\mathcal{M}$ is the mass of a mole of the substance (molar mass) (measured in kg)

✧ **To find the number of moles n :**

$$\boxed{n = \frac{N}{N_A}} \quad \text{or} \quad \boxed{n = \frac{\text{M}}{\mathcal{M}}}$$

✧ **To find the number of atoms N :**

$$\boxed{N = \frac{\text{M}}{\mathcal{M}} N_A}$$

$A = kN$

M — N — A

$N = \frac{M}{\mathcal{M}} \cdot N_A$

✧ **The molar mass of an isotope is the mass number in** g, e.g. molar mass of C-14 is 14 g.

Example : The mass of 1 mole of plutonium-238 is 238 g. Plutonium decays by emitting on α particle, with half-life of 87.7 years. A rock contains 5 g of plutonium-238. Calculate the activity of the plutonium-238 in the rock.

$$N = \frac{5}{238} \times 6.02 \times 10^{23} = 1.265 \times 10^{22}$$

M → N → A

$$\boxed{k = \frac{\ln 2}{t_{1/2}}} = \frac{\ln 2}{87.7 \times 365 \times 24 \times 3600} = 2.506 \times 10^{-10}\ \text{s}^{-1}$$

$$\boxed{A = kN} = (2.506 \times 10^{-10}) \times (1.265 \times 10^{22}) = 3.17 \times 10^{12}\ \text{Bq}$$

Example : {2012} 1 curie (Ci) is defined as the activity of 1 g of radium. The activity of a radium source used in laboratories is about 5 μCi. Estimate the number of radium atoms in this source and hence find its activity expressed in disintegrations per second. The half-life of radium-226 is 1600 years and take the mass of one mole of radium as 226 g.
(1 μCi = 1 × 10⁻⁶ Ci) (3 marks)

Mass of radium = 5 μg $\quad \therefore\ N = \frac{5 \times 10^{-6}}{226} \times 6.02 \times 10^{23} = 1.332 \times 10^{16}$

$$k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{1600 \times 365 \times 24 \times 3600} = 1.374 \times 10^{-11}\ \text{s}^{-1}$$

M → N → A

$$A = kN = (1.374 \times 10^{-11}) \times (1.332 \times 10^{16}) = 1.83 \times 10^{5}\ \text{Bq}$$

2. Radioactive decay (放射衰變)

(i) Conservation Laws (守恆定律)

✧ **In all radioactive transmutation (放射性遷變), the following two laws must be obeyed :**

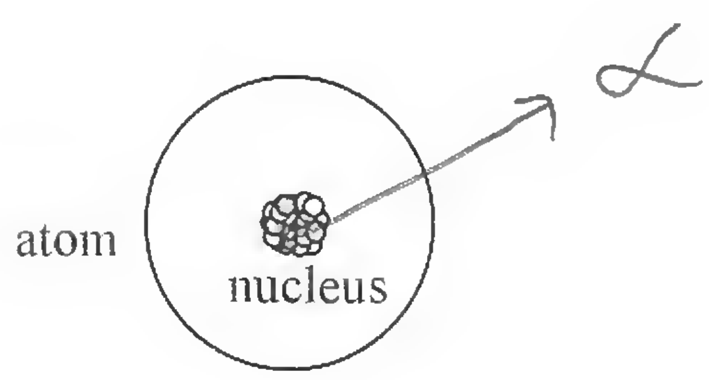
① **Conservation of Mass** (質量守恆)

The total mass number A (質量數) must be balanced at both sides in the nuclear equation.

② **Conservation of Charge** (電荷守恆)

The total atomic number Z (原子序數) must be balanced at both sides in the nuclear equation.

(ii) Alpha decay (α衰變)



✧ **Alpha decay occurs in a large unstable nucleus.**

$$^{A}_{Z}X \longrightarrow {}^{4}_{2}\alpha + {}^{A-4}_{Z-2}Y$$

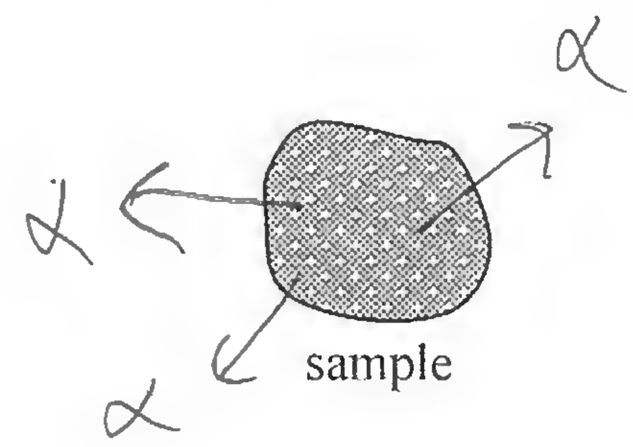
mother nucleus — daughter nucleus

✧ **After the decay, the mother nucleus transmutes to the daughter nucleus which is another element.**

✧ **For the new element, its atomic number is decreased by 2 and its mass number is decreased by 4.**

e.g. $$^{238}_{92}U \longrightarrow {}^{4}_{2}He + {}^{234}_{90}X$$

✧ **Since the mass of α is negligible compared with the mass of the mother nucleus, the mass of the sample remains unchanged after the decay.**



Example (2001) : Radium $\left(^{226}_{88}Ra\right)$ decays by emitting an α particle to form a product nucleus X. Which of the following shows the correct equation for this decay ?

A. $^{226}_{88}Ra + \alpha \rightarrow {}^{230}_{90}X$

B. $^{226}_{88}Ra \rightarrow {}^{224}_{84}X + \alpha$

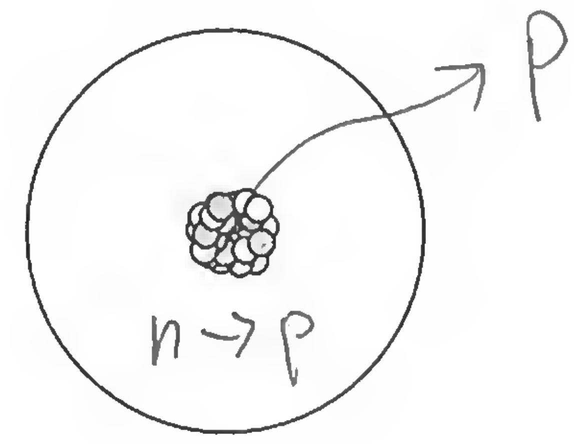
C. $^{226}_{88}Ra \rightarrow {}^{222}_{86}X + \alpha$

D. $^{226}_{88}Ra \rightarrow {}^{226}_{89}X + \alpha$

(iii) Beta decay (β衰變)

✧ **Neutron (中子) is unstable. It may decay to form a proton and an electron.**

$$ {}^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e} \rightarrow \text{P} $$



✧ **When a nucleus contains too many neutrons, it may undergo β-decay to form a new element.**

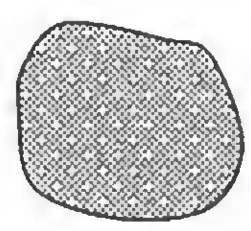
$$ \underset{\text{mother nucleus}}{{}^{A}_{Z}\text{X}} \longrightarrow {}^{0}_{-1}\beta + \underset{\text{daughter nucleus}}{{}^{A}_{Z+1}\text{Y}} $$

✧ **Compared with the mother nucleus, after the β decay, the daughter nucleus has**

- ✲ the number of neutrons decreased by 1
- ✲ the number of protons increased by 1
- ✲ the mass number been unchanged
- ✲ the atomic number increased by 1

e.g. ${}^{234}_{91}\text{Pa} \longrightarrow {}^{0}_{-1}\text{e} + {}^{234}_{92}\text{X}$

✧ **Since the mass of β is negligible compared with the mass of the mother nucleus, the mass of the sample remains unchanged after the decay.**



sample

Example : β particles are emitted from the radioactive nucleus in a β decay. T | β particles are fast moving electrons. T
(2009)

Example : A thorium nucleus (${}^{234}_{90}\text{Th}$) decays by emitting a β particle to form a daughter nucleus X. Which of the following equations represents this decay ?
(2005)

A. ${}^{234}_{90}\text{Th} \longrightarrow {}^{230}_{88}X + \beta$

B. ${}^{234}_{90}\text{Th} \longrightarrow {}^{234}_{89}X + \beta$

C. ${}^{234}_{90}\text{Th} \longrightarrow {}^{233}_{90}X + \beta$

D. ${}^{234}_{90}\text{Th} \longrightarrow {}^{234}_{91}X + \beta$

Example : A nucleus X emits a beta particle to form a daughter nucleus Y. Which of the following statements is/are correct ?
(1998)

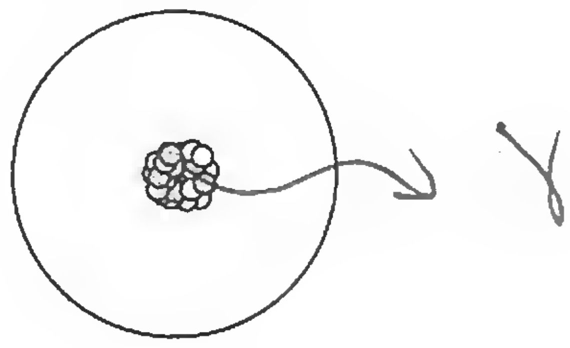
(1) X and Y have the same number of neutrons. → −1
(2) The number of protons in X is greater than that in Y by 1.
(3) The total numbers of neutrons and protons in X and Y are equal. same A

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y$$

(iv) Gamma emission (γ 輻射)

- **The nucleus releases excess energy in form of γ-radiation.**

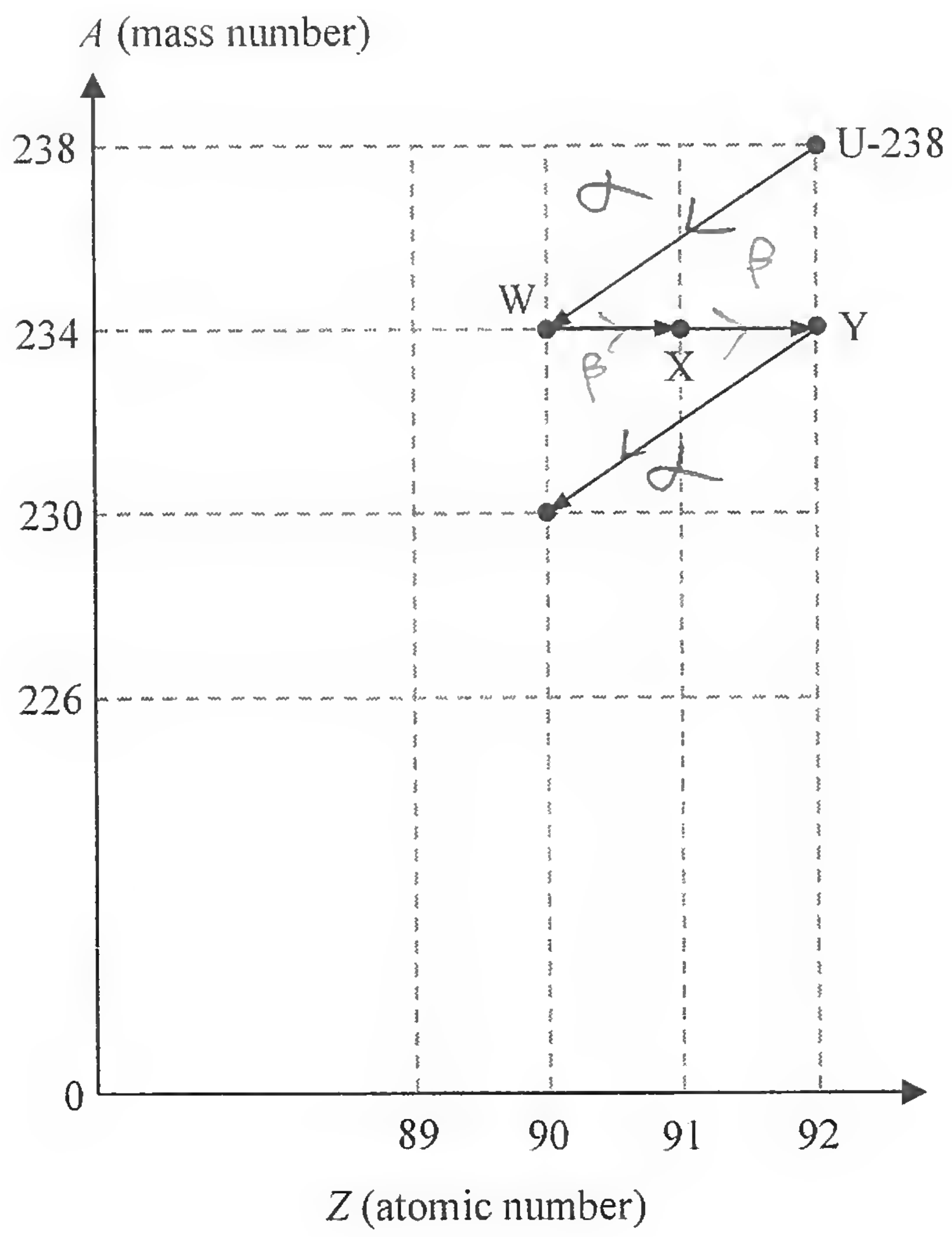


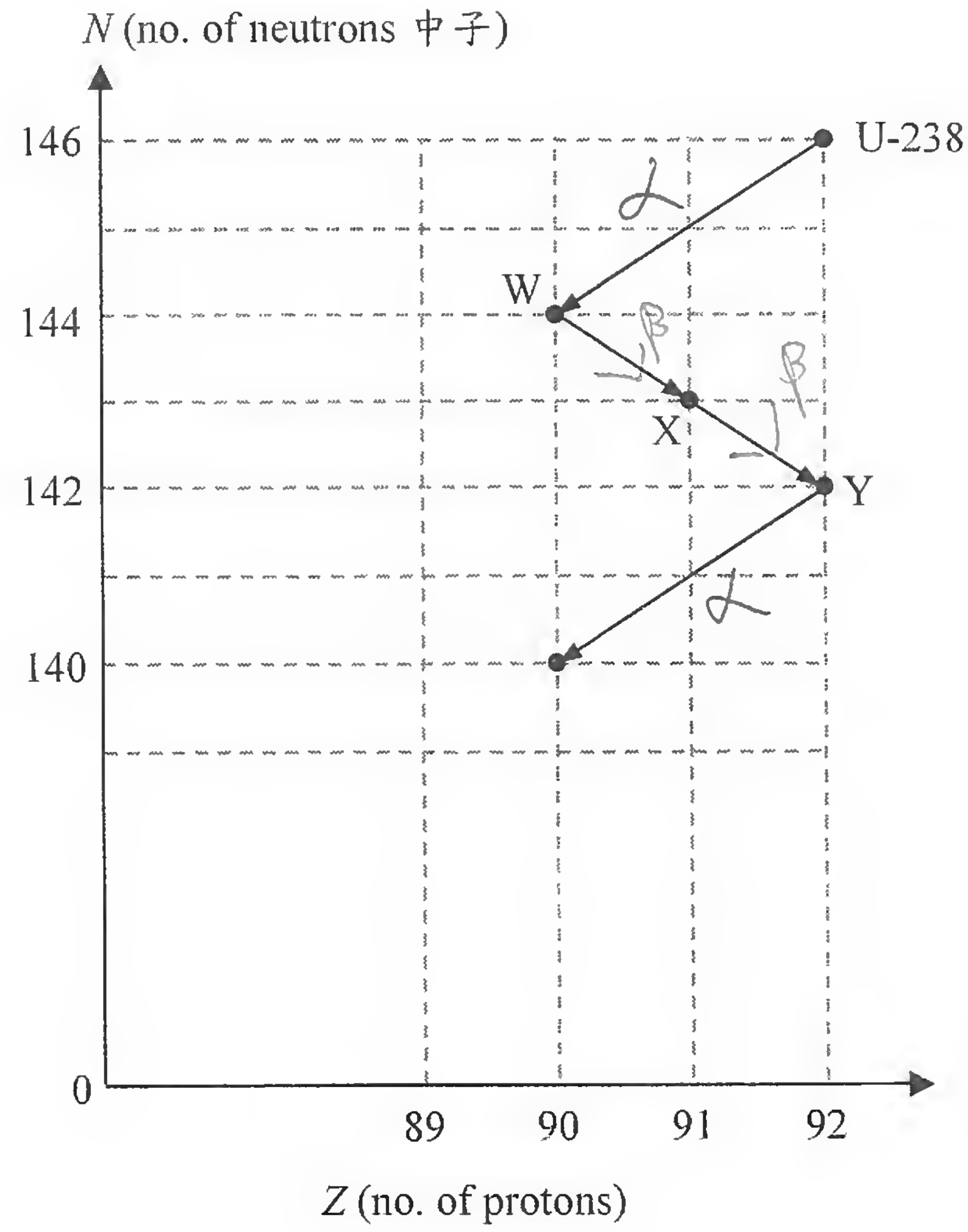
- **After the γ-emission :**
  - there is no change of the mass number and the atomic number of the atom
  - no new element is formed

(v) Radioactive series (衰變系列)

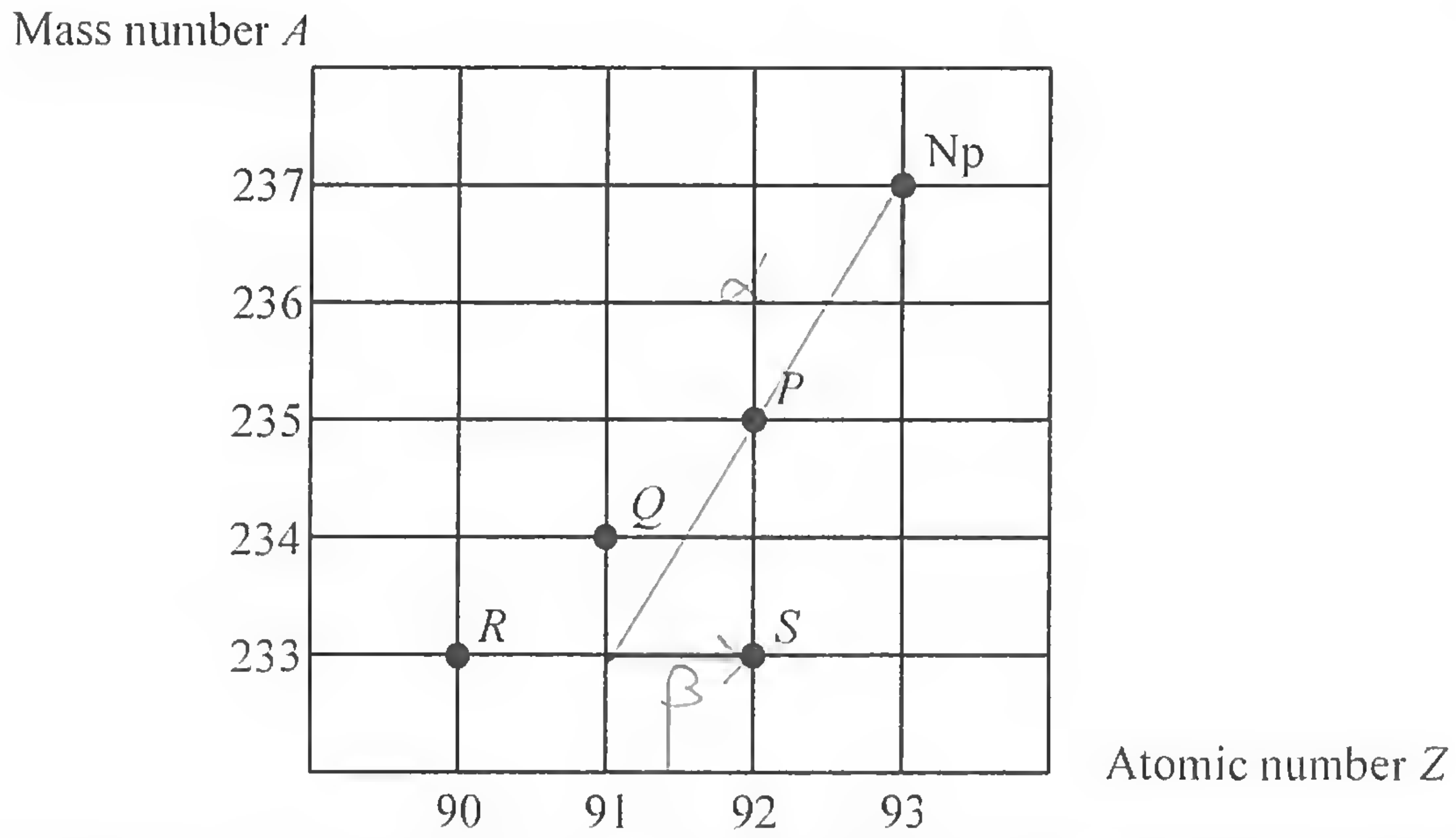
- **Most large radioactive isotopes will follow a series of decays to emit α and β particles in a definite order.**
- **Since no new element is formed for emission of γ-radiation, γ-emission is not indicated in the figure.**
- **The final stable product is usually lead (鉛).**
- **Example of a series :**

$$^{238}_{92}U \xrightarrow{\alpha} {}^{234}_{90}W \xrightarrow{\beta} {}^{234}_{91}X \xrightarrow{\beta} {}^{234}_{92}Y \xrightarrow{\alpha}$$





Example :
(1999)



The above diagram shows the mass number A and atomic number Z of a few nuclides. The isotope of neptunium (Np) shown decays by emitting an α particle and then a β particle. Which of the following represents the resulting nuclide ?

A. P B. Q C. R D. S

Example : A radioactive nuclide W decays to a nuclide Z by emitting one α-particle and two β-particles as shown below.
(1995)

$${}^{100}_{50}W \xrightarrow{\beta} {}^{100}_{51}X \xrightarrow{\alpha} {}^{96}_{49}Y \xrightarrow{\beta} {}^{96}_{50}Z$$

Which of the following statements about nuclides W, X, Y and Z is/are correct ?

✓ (1) W and Z are isotopes.

(2) X has the greatest atomic number.

(3) Y has the greatest mass number.

A. (1) only B. (3) only C. (1) & (2) only D. (2) & (3) only

Example :
(2006)

$$52\ X \xrightarrow{\alpha} 50\ Y \xrightarrow{\beta} 51\ Z$$

$$50\ P \xrightarrow{\beta} 51\ Q \xrightarrow{\beta} 52\ R \xrightarrow{\alpha} 50\ S$$

In the above two decay series, P and Y are two isotopes. Which of the following pairs of nuclides are isotopes to each other ?

(1) X and R
(2) Y and S
(3) Z and Q

A. (1) & (2) only B. (1) & (3) only C. (2) & (3) only D. (1), (2) & (3)

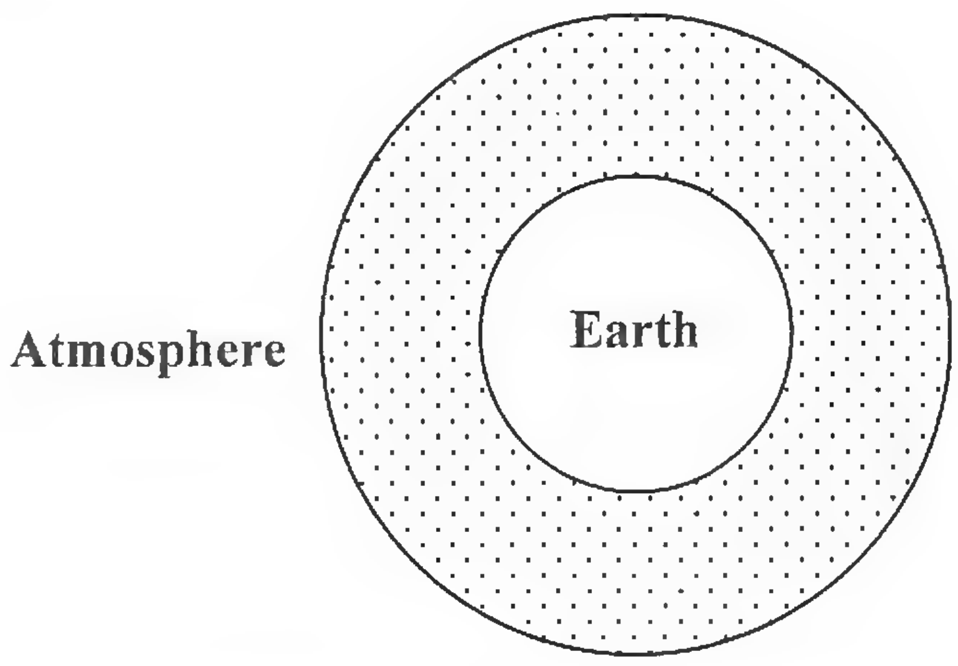
Example : A radioactive isotope ${}^{234}_{90}Th$ undergoes a series of decay processes to form a daughter ${}^{206}_{82}Pb$. How many α-particles and β-particles have been emitted in this decay process ?
(2002)

	No. of α-particles	**No. of β-particles**
A.	6	7
B.	7	6
C.	7	8
D.	8	7

$${}^{234}_{90}Th \to {}^{206}_{82}Pb + a({}^{4}_{2}He) + b({}^{0}_{-1}e)$$

3. Applications of radioactivity（放射性的應用）

(i) Carbon-14 dating（碳14年代測定法）



- Carbon-14 is a radioisotope of carbon exists in a very small proportion in the atmosphere. It is produced by the bombardment of nitrogen-14 by the neutron created by cosmic rays.

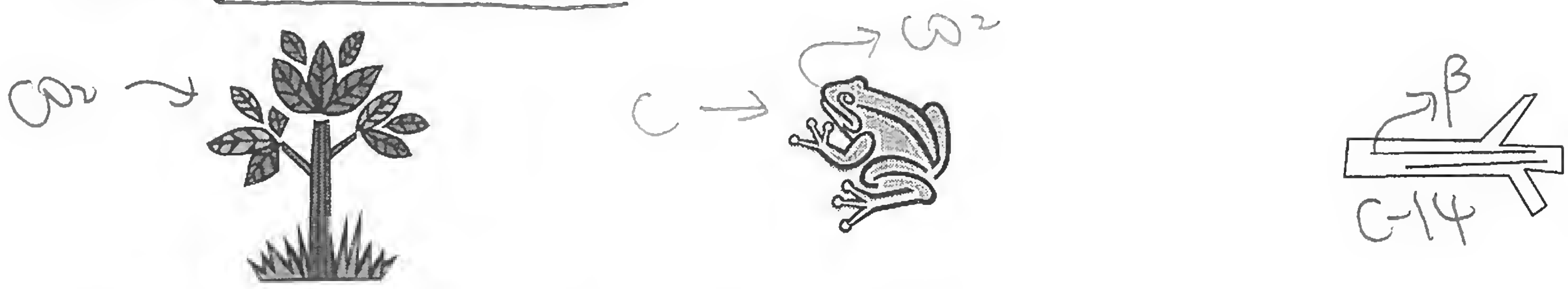
$$^{14}_{7}\mathrm{N} + ^{1}_{0}\mathrm{n} \longrightarrow ^{14}_{6}\mathrm{C} + ^{1}_{1}\mathrm{p}$$

- Carbon-14 undergoes β-decay with a half-life of about 5700 years.

$$^{14}_{6}\mathrm{C} \longrightarrow ^{0}_{-1}\beta + ^{14}_{7}\mathrm{N}$$

- Living plants take in carbon dioxide for photosynthesis and animals eat food. They also give out carbon dioxide by respiration. Thus, the relative abundance of carbon-14 atoms inside a living organism stays constant and equals to that of the atmosphere due to this exchange.

- The proportion of C-14 to C-12 (relative abundance of C-14) is assumed to remain constant over the past thousands of years.



- After death, there is no exchange of carbon with the environment. Thus, the number of carbon-14 atoms inside the organism starts to decrease.

- By comparing the activity of the dead organism with that of a living organism, the age of the organism can be estimated.

- This method is used in archaeological study（考古學）and is most suitable to date materials about several thousand years old.

- Advantages of using carbon-14 for dating archaeological samples
  - Carbon exists in all living organism.
  - Carbon is chemically stable.

Example : (2007) In the upper atmosphere, neutrons are produced by the action of cosmic rays. These neutrons interact with nitrogen nuclei as shown in the following reaction:

$$ {}^{1}_{0}\text{n} + {}^{14}_{7}\text{N} \rightarrow {}^{14}_{C}X + {}^{1}_{1}\text{H} $$

Element X will then emit a β particle. The reaction is as follows :

$$ X \rightarrow Y + {}^{0}_{-1}\beta $$

What is the final product Y ?

A. ${}^{14}_{6}\text{C}$

B. ${}^{13}_{6}\text{C}$

C. ${}^{14}_{7}\text{N}$

D. ${}^{13}_{7}\text{N}$

Example : (1984) An ancient piece of wood was tested for its age by carbon 14 dating method. The normal emission rate from 2 g of carbon from a living plant is 20 counts per minute. If the rate from 2 g of carbon from the wood is 5 counts per minute, and the half life of carbon 14 is 5700 years, what is the approximate age of the wood in years ?
(Background radiation may be neglected.)

A. 5700 × 4

B. 5700 × 2

C. 5700 / 2

D. 5700 / 4

$20 \rightarrow 10 \rightarrow 5$

$2t_{\frac{1}{2}}$

Example : {2013} Carbon-14 dating can be used to identify the age of some objects which have the ^{14}C isotope, as it is radioactive and decays by emitting a β-particle. A piece of wood sample is examined using carbon-14 dating and its activity is 0.2 Bq. The half-life of ^{14}C is 5730 years. Given : 1 year = 3.16×10^7 s

(a) Calculate the decay constant of ^{14}C in s^{-1}. Hence find the number of ^{14}C nuclei in this wood sample. (3 marks)

$$ k = \frac{\ln 2}{5730 \times 3.16 \times 10^7} = 3.83 \times 10^{-12}\ \text{s}^{-1} \quad [1] $$

$A \rightarrow N$

By $A = kN$

$$ \therefore\ (0.2) = (3.83 \times 10^{-12})\,N \quad [1] $$

$$ \therefore\ N = 5.22 \times 10^{10} \quad [1] $$

Assume that living organisms contain a constant proportion of carbon-14 in the ratio of $\boxed{^{14}C / ^{12}C = 1.3 \times 10^{-12}}$ during its life time via intake of carbon dioxide (CO_2) from the atmosphere.

(b) The carbon content of this wood sample is found to contain a total of 1×10^{23} carbon nuclei. Estimate the number of ^{14}C nuclei in the sample originally when it died. (1 mark)

$$ N_o = \underline{(1 \times 10^{23})} \times (1.3 \times 10^{-12}) = 1.3 \times 10^{11} \quad [1] $$

(c) Estimate the age of this wood sample in years using the results found in (a) and (b). (2 marks)

$$ \boxed{N = N_o e^{-kt}} $$

$N = N_0 (\frac{1}{2})^{t/t_{\frac{1}{2}}}$

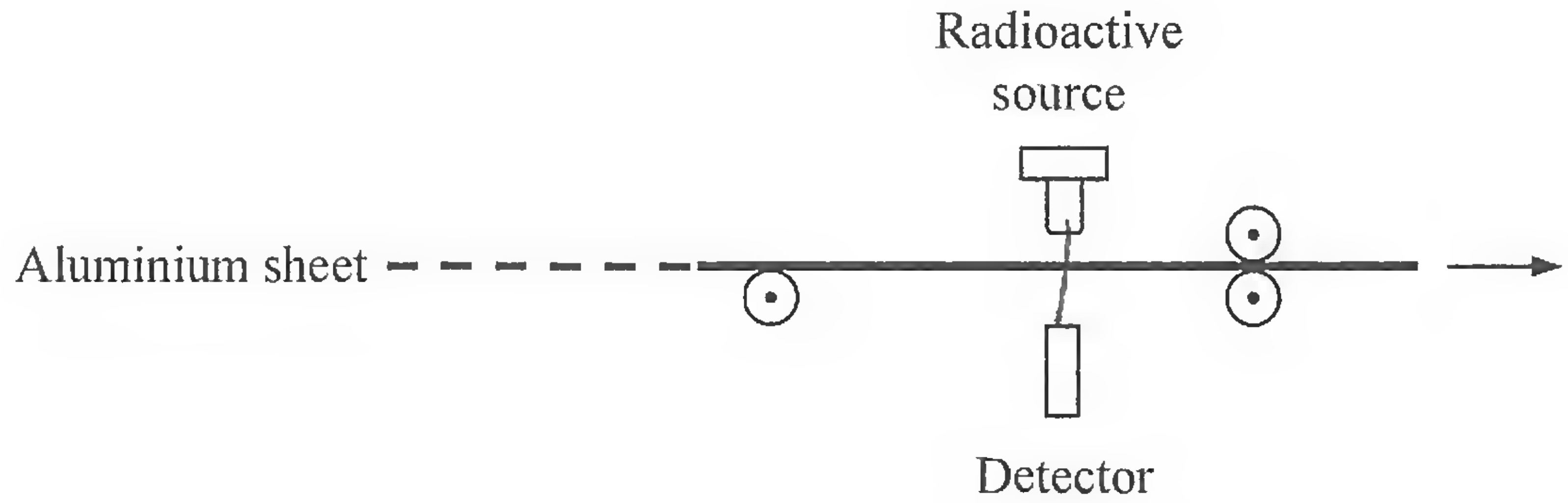
$$ (5.22 \times 10^{10}) = (1.3 \times 10^{11})\ e^{-(3.83\times10^{-12})t} \quad [1] $$

$$ \therefore\ t = 2.38 \times 10^{11}\ \text{s} = 7540\ \text{years} \quad [1] $$

(ii) Thickness gauge (厚度計)

✧ **It is used to monitor (監控) the thickness of aluminium sheets** (or common metal sheets).

✧ **Working principle of the thickness gauge :**



① A radioactive source is placed on one side of the aluminium sheet.

② Radiation emitted from the source is partly absorbed and partly penetrates through the aluminium sheet to reach the other side.

③ A GM tube used as a detector is placed on the other side to record the normal reading.

④ If the aluminium sheet is too thin, less radiation has been absorbed and thus the counter will record a reading significantly higher than normal.

⑤ If an aluminium sheet is too thick, more radiation would be absorbed and thus the counter will record a reading significantly lower than normal.

⑥ Note that if there is slight variation, it is only due to the random nature of radiation.

✧ **Choice of the type of radiation :**

✗ ① α-radiation cannot be used since α cannot penetrate through the aluminium sheet.

✓ ② β-radiation should be used since β is partly absorbed and partly penetrates through the aluminium sheets and thus it is sensitive to the thickness of the aluminium sheet.

✗ ③ γ-radiation cannot be used since γ is too penetrating and is not affected by the thickness of aluminium.

✧ **For the use of radioisotope in thickness gauge, the half-life of the radioisotope should be long due to the following 2 reasons :**

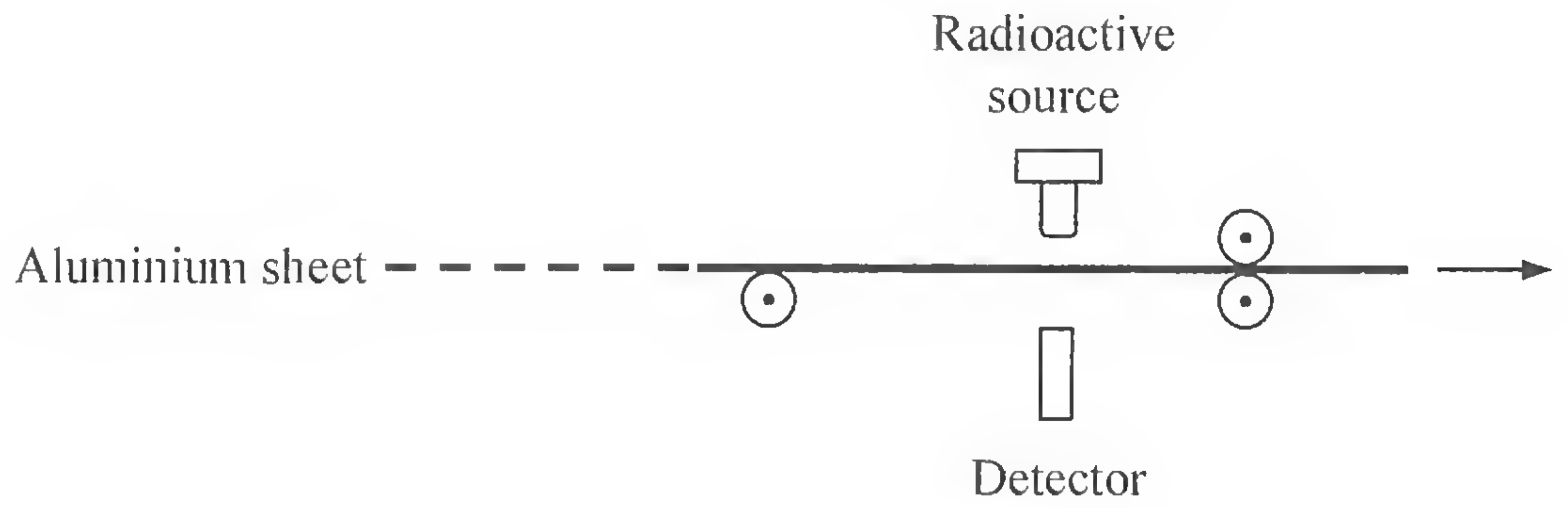
✲ the activity of the source will be stable as the source decays slowly

✲ the source can be used for a long time and no need to replace frequently

✧ **Typical order of half-life of radioisotopes :** year

✧ **Other applications making use of the penetrating power of β radiation have similar working principles as the thickness gauge.**

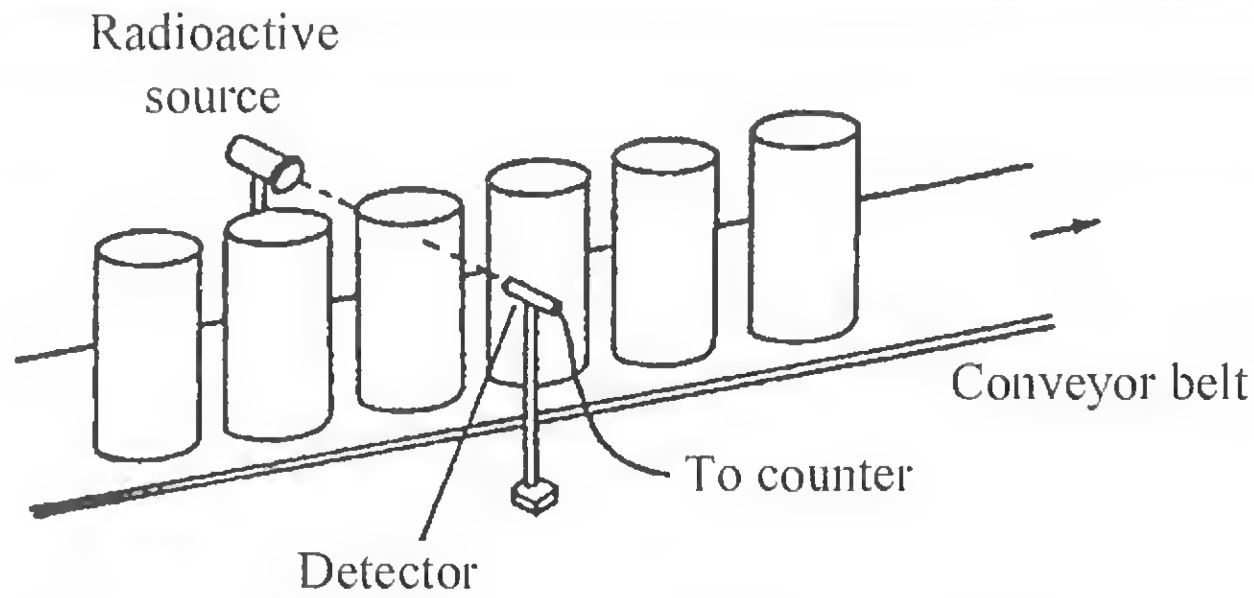
Example :
(1998)



In a factory producing aluminium sheets of 1 mm thickness, a thickness gauge is used to monitor the thickness of aluminium sheets. Which of the following states the correct radioactive source to be used in the thickness gauge and the reason behind ?

	Source	**Reason**
A.	α	The amount of α particles passing through aluminium depends on its thickness.
B.	β	The amount of β particles passing through aluminium depends on its thickness.
C.	β	β particles are less harmful to human beings.
D.	γ	γ radiation has the greatest penetrating power.

Example :



A factory produces detergent contained in plastic bottles. The following method is used to monitor the amount of detergent contained in each bottle : the bottles are placed on a conveyor belt; a radioactive source is placed on one side of the conveyor belt at the level to which the detergent is expected to fill and a detector is placed at the same level on the other side as shown in the figure above. The monitoring system can detect bottles of detergent that have not been filled up to the required level.

Source	Half-life	Type of radiation emitted
P	4 years	α
Q	10 minutes	β
R	2 years	β
S	6 minutes	γ
T	1 year	γ

The table shows some radioactive sources. Which of the sources is the most suitable one to be used in the above monitoring system ? Explain why the other four are **not** suitable. (4 marks)

R is the most suitable. [1]

P is not suitable since the penetrating power of α is too low. [1]

Q is not suitable since the half-life is too short and the activity will not be stable. [1]

S and T are not suitable since γ has too large penetrating power. [1]

Example : (a) (2000) X and Y are two radioactive nuclides with half lives of 12 hours and 2.6 years respectively. Both two nuclides decay by emitting a β particle to form stable product nuclides.

(i) After emitting a β particle, how would the atomic number and mass number of nuclide X be changed ? (2 marks)

The atomic number increases by one. [1]

The mass number remains unchanged. [1]

(ii) Describe the changes in activity (in disintegrations per second) of a specimen of nuclide X and a specimen of Y after one day. (2 marks)

The activity of specimen X will fall to a quarter of its original value. [1]

The activity of specimen Y will remain unchanged. [1]

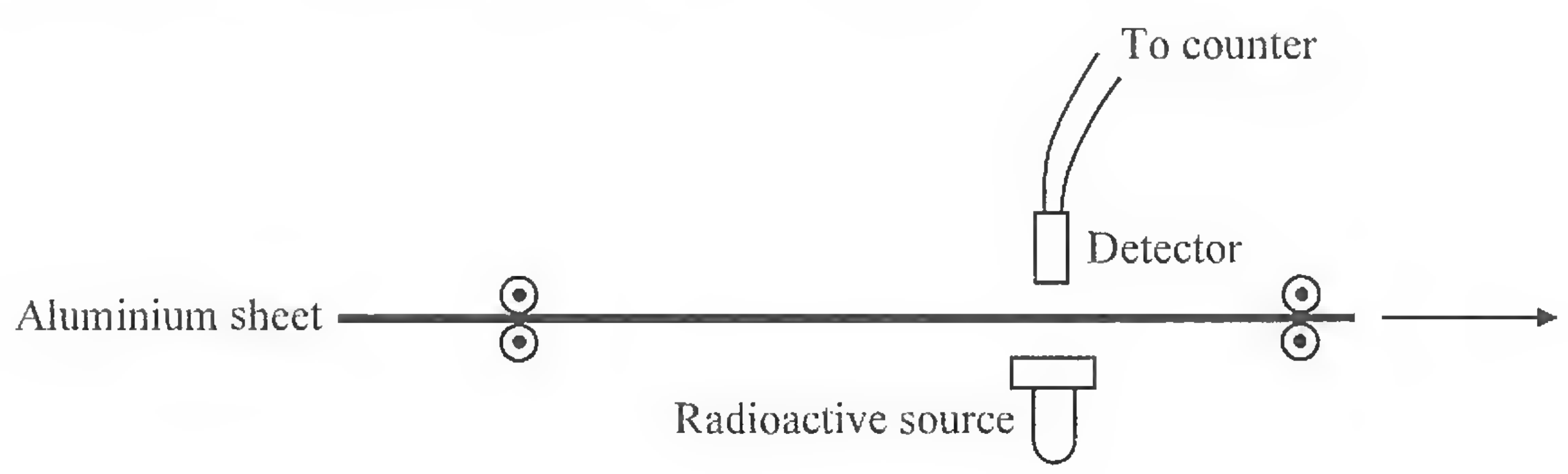
(iii) Comment on the following statement :

The mass of a specimen containing nuclide X will be reduced by approximately half in 12 hours. (2 marks)

As the mass of β particles is very small, [1]

the mass of the specimen would almost remain unchanged after 12 hours. [1]

(b) A factory produces aluminium sheets 1 mm in thickness. The thickness of the sheets is monitored by a gauge as shown in the figure below. A β source is used in the gauge.



(i) Explain why α and γ sources are not used in the gauge. (2 marks)

α source is not used because the penetrating power of α particles is too low. [1]

γ source is not used because the penetrating power of γ radiation is too high. [1]

(ii) Which of the nuclides (X or Y) is more suitable to use as the radioactive source ? Explain your answer. (2 marks)

Nuclide Y is more suitable. [1]

As nuclide Y has a longer half-life, its activity remains stable over a longer period of time. [1]

(iii) The count rate recorded should be around 90 counts per second when the thickness of the aluminium sheet is 1 mm. On a certain day when the gauge is operating properly, the following data are recorded :

Time / s	0	10	20	30	40	50	60	70	80	90	100
Recorded count rate / counts per s	90	89	91	90	90	88	66	64	90	89	89

Describe and explain the variation in the readings in the above table. (4 marks)

The reading remains steady from t = 0 to 50 s and from t = 80 to 100 s. [1]

The small variation within this period is due to the random nature of radioactive decay. [1]

The reading drops significantly from t = 60 to 70 s. [1]

The aluminium sheet in this period is thicker than the normal value. [1]

(iii) Medical tracer (醫療示蹤物)

✧ **A small amount of weak radioactive isotope can be used as a tracer and be injected into a system of the human body. The flow of the radioisotope can then be traced by a GM tube outside the human body.**

✧ **Examples of using a medical tracer :**

① To investigate the blood circulation of a patient (研究病人的血液循環系統).

② To test the proper functioning of the human organs (測試人體器官的正常運作).

✧ **Choice of type of radiation for using as a tracer :**

① α-radiation cannot be used since its penetrating power is too weak that it cannot penetrate through the human body. Moreover, its strong ionizing power causes much harmful effect to the human body.

② β-radiation may be used if the test is just under the surface tissue of the human body but cannot be used if the organ is well inside the human body.

③ γ-radiation should be used since it has the largest penetrating power and can be detected outside the human body. Moreover, it causes the less harmful effect to the human body

✧ **Choice of the half life of the radioisotope for a tracer :**

✲ The half-life should not be too short (long enough) in order to have enough time for the doctor to diagnose (診斷).

✲ The half-life should not be too long (short enough) in order to cause less harmful effect to the human body.

✧ **Choice of the order of the half-life :**

second minute	$\boxed{\text{hour day}}$	month year
too short	suitable	too long

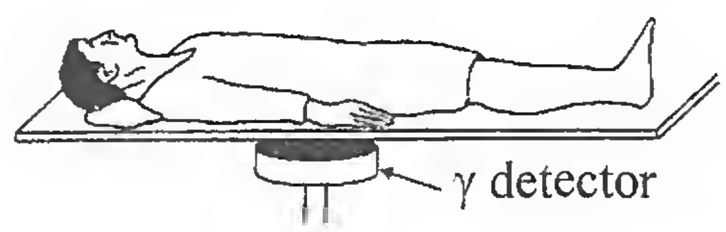
Example : Which of the following are essential criteria in choosing radioactive sources as medical tracers in human bodies ?
(2003) ✓(1) The sources should have a short half-life.
✓(2) The radiation emitted should have a weak ionizing power.
✗ (3) The radiation emitted should not be deflected by an electric field.
有关

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

Example : (2000) α sources are not suitable for injection into human bodies as medical tracers. T

α particles carry positive charges and can be deflected by electric field. T

Example :
(2002)



Iodine-131 ($^{131}_{53}I$) is a radioisotope which decays by emitting a β-particle and γ rays. It is used in hospitals to test the kidneys of patients. During the test, an iodine-131 solution is injected into the bloodstream of a patient. As the blood passes through the kidney, iodine-131 will be absorbed by the kidney and eventually excreted out of the body with urine. If the kidney is not functioning properly, both the absorption and excretion rates of iodine-131 will decrease. A γ-detector is placed near the kidneys of the patient to detect the activity of the radiation coming from the kidneys as shown in the above figure.

(a) Using X to denote the daughter nucleus, write down an equation for the decay of an iodine-131 nucleus. (2 marks)

$$^{131}_{53}I \longrightarrow {}^{131}_{54}X + {}^{0}_{-1}\beta \boxed{+ \gamma}$$ 可以不写. [2]

(b) Explain why the β-particles emitted by iodine-131 fail to reach the detector. (1 mark)

The β particles cannot pass through the human body. [1]

(c) The half-life of iodine-131 is 8 days.

(i) State the meaning of 'half-life'. (2 marks)

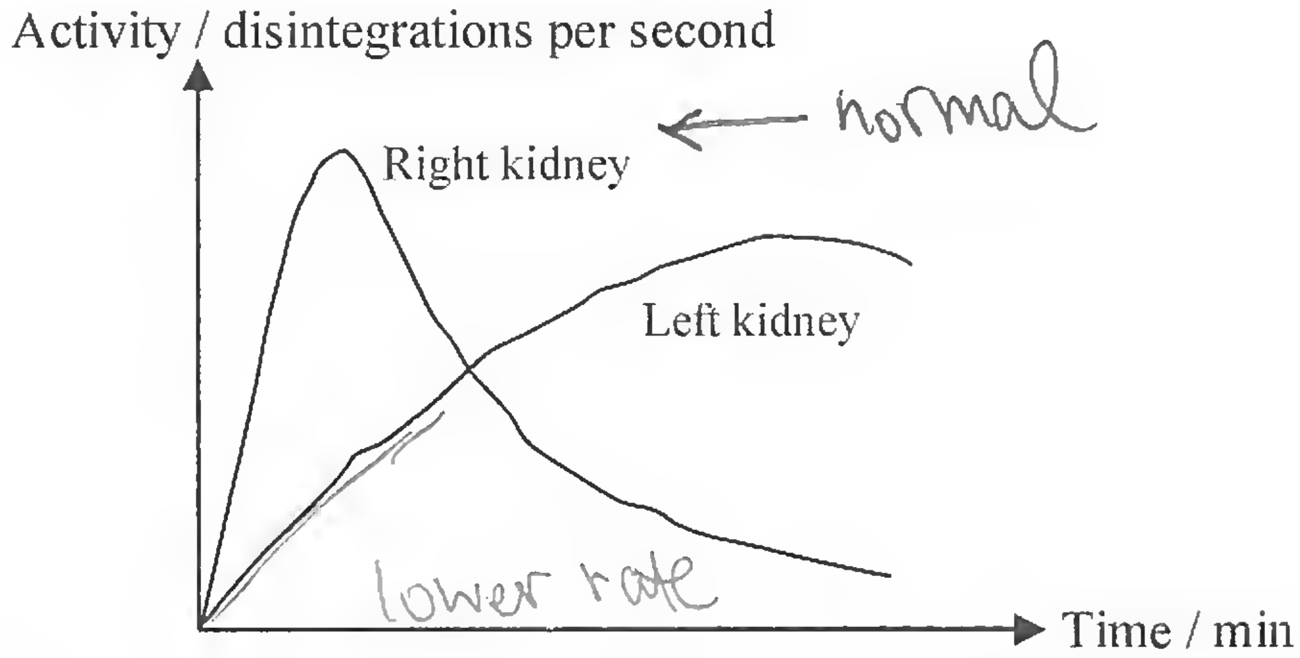
The half-life is the time taken for the activity of the source to drop to half of its initial value. [2]

(ii) For safety purposes, the activity of iodine-131 solution in the test should not exceed 1.5×10^8 disintegrations per second. When an iodine-131 solution is prepared, its activity is 6×10^8 disintegrations per second. How many days after preparation would the solution be suitable for the test ? (2 marks)

No. of half-life = 2 [1]

The solution is suitable after $2 \times 8 = 16$ days [1]

(iii)



The above graph shows the variation of the activities of the radiation detected from the right and left kidneys of a patient with time. Which kidney do you think is **not** functioning properly ? Explain your answer. (3 marks)

The left kidney is not functioning properly [1]

since the activity in the left kidney increases at a lower rate. [2]

(iv) Besides iodine-131, technetium-99*m* is another radioisotope that can be used in the kidney test. Technetium-99*m* emits γ radiation only and its half-life is 6 hours. Which of these two sources do you think is more preferable for use in the kidney test ? Explain your answer. (4 marks)

Technetium-99*m* is more preferable than iodine-131 for use in the test. [1]
Since technetium-99*m* has a shorter half-life [1]
and does not emit β particles, [1]
so it causes less harmful effect to the patient. [1]

Example : Read the following passage about Iodine-131 therapy and answer the questions that follow. (2005)

Iodine-131 is a radioisotope which emits β and γ radiation. It can be used for thyroid cancer treatment.

A patient suffering from thyroid cancer will first undergo an operation to have the thyroid gland removed. However, some thyroid tissue may remain in the neck of the patient or may be carried in the blood stream to other parts of the body. Iodine-131 is then used to trace and get rid of the remaining thyroid tissue in the body.

Iodine-131 therapy consists of two stages. In Stage 1, the patient will take a low dose of Iodine-131 to trace the remaining thyroid tissue. A detector is placed near the patient to monitor the activity of the radiation coming from the patient.

In case any remaining thyroid tissue is spotted in Stage 1, the patient will then take a higher dose of Iodine-131 in Stage 2. The iodine will be absorbed by the thyroid tissue and the radiation emitted can kill the cancer cells.

Special hospital rooms are designed for patients who receive Stage 2 of the therapy. The rooms have metallic shielding in the doors and reinforced walls. Inside the rooms, there are plastic covers on the furniture, doors, handles and switches.

(a) Explain why, in Stage 1, β radiation from the patient cannot be detected by the detector. (1 mark)

The penetrating power of β radiation is too low. [1]

OR

β radiation cannot penetrate through human body. [1]

(b) In Stage 2, which kind of radiation is more effective in killing cancer cells? Explain your answer. (2 marks)

β radiation is more effective in killing cancer cells. [1]

Since the ionizing power of β is higher than that of γ radiation. [1]

(c) State one special feature of the hospital rooms designed for patients receiving Stage 2 of the therapy and explain its function. (2 marks)

The rooms have metallic shielding in the doors and walls. [1]

They can prevent radiation from leaking out of the rooms. [1]

OR

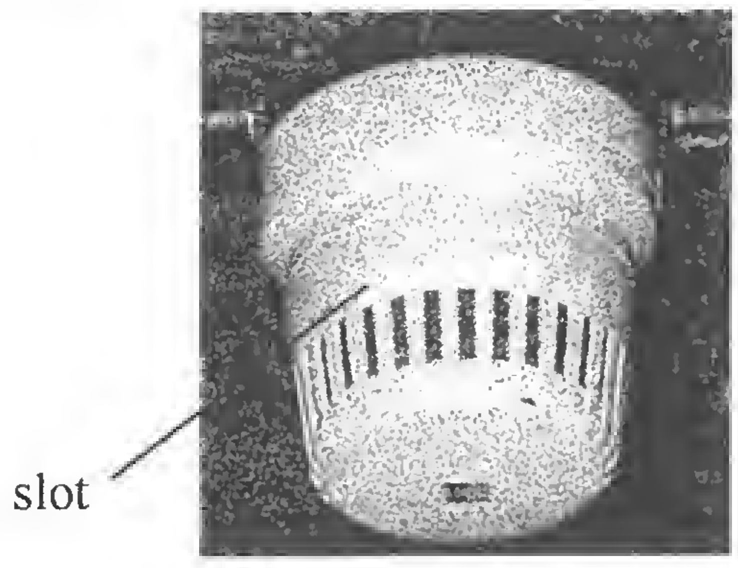
Inside the rooms, there are plastic covers on the furniture, doors, handles and switches. [1]

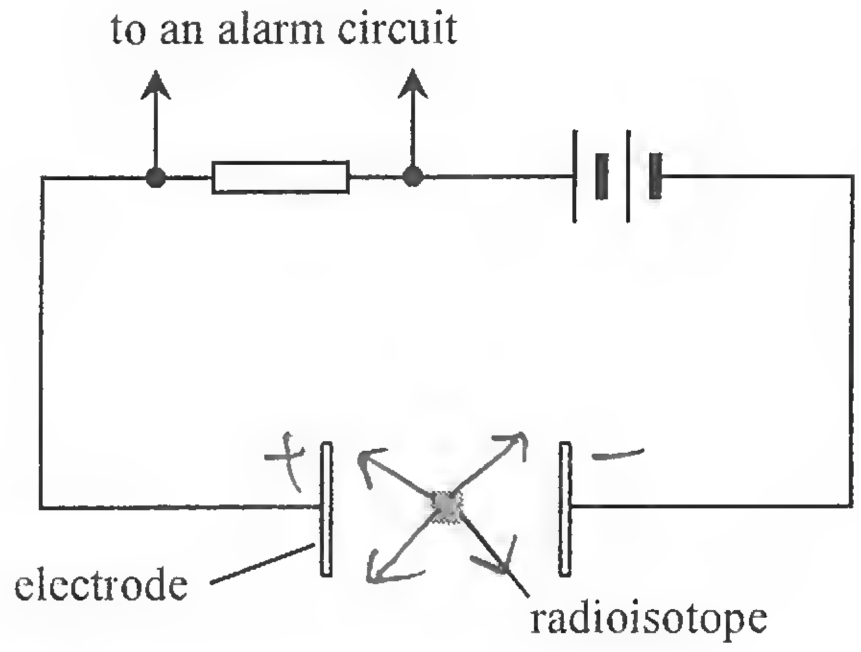
This prevents other persons using the room from being contaminated. [1]

(iv) Radiotherapy (放射性治療)

- ✧ **Cobalt-60 is a strong source of γ-radiation. It is commonly used to kill cancer cells (癌細胞).**
- ✧ **Gamma-radiation is used since it is more penetrating on passage into the human body and is able to destroy the cancer cells in preference to the healthy cells.**
- ✧ **The half-life of the source should be long so that it can be used for a long time.**
- ✧ **The radiation with large dose must be carefully directed and localized at the cancer site by collimation through lead slits.**
- ✧ **It is operated by remote control (遙控) and heavily shielded by lead glasses.**

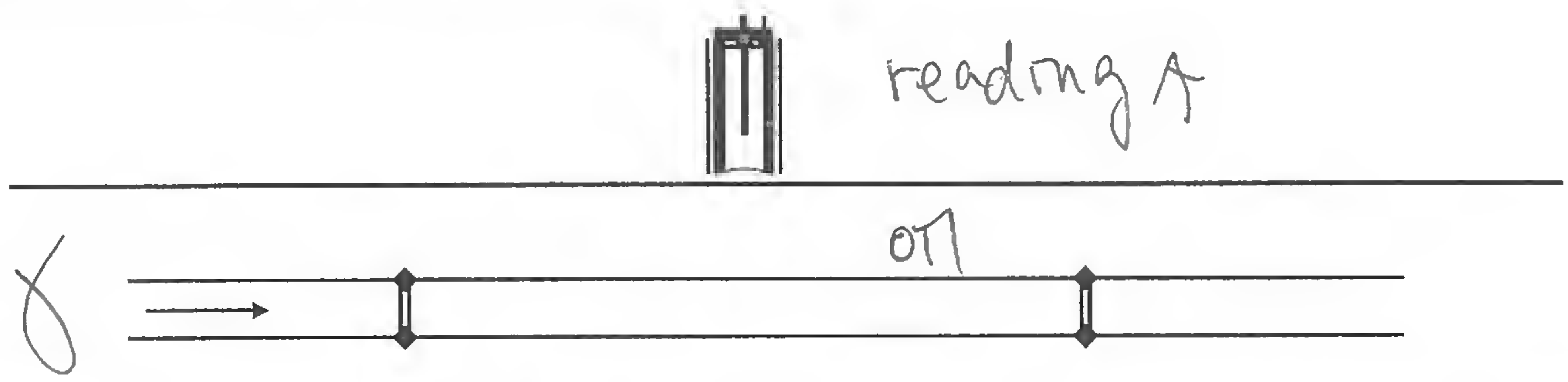
(v) Smoke detection (煙霧探測器)





- Smoke detectors can give alarm sound (警鐘鳴響) when smoke is detected.
- The smoke detector is attached to the ceiling inside a building. It has slots to allow air flow into the detector.
- Inside the detector, a small amount of radioisotope emitting α particles is placed between the two electrodes. The two electrodes are connected to a battery and an alarm circuit.
- Under normal condition, the α particles will ionize the air and the ions are attracted to the two electrodes to conduct a small current.
- When there is smoke, smoke particles enter the detector and block (阻礙) the flow of ions. Thus the current drops and the circuit triggers (引發) the alarm to sound.
- The half-life of the radioisotope should be long so that
  - the source can be used for a long time and no need to replace frequently
  - the activity of the source remains stable as the source will decay slowly

(vi) Leakage detection (泄漏探測)

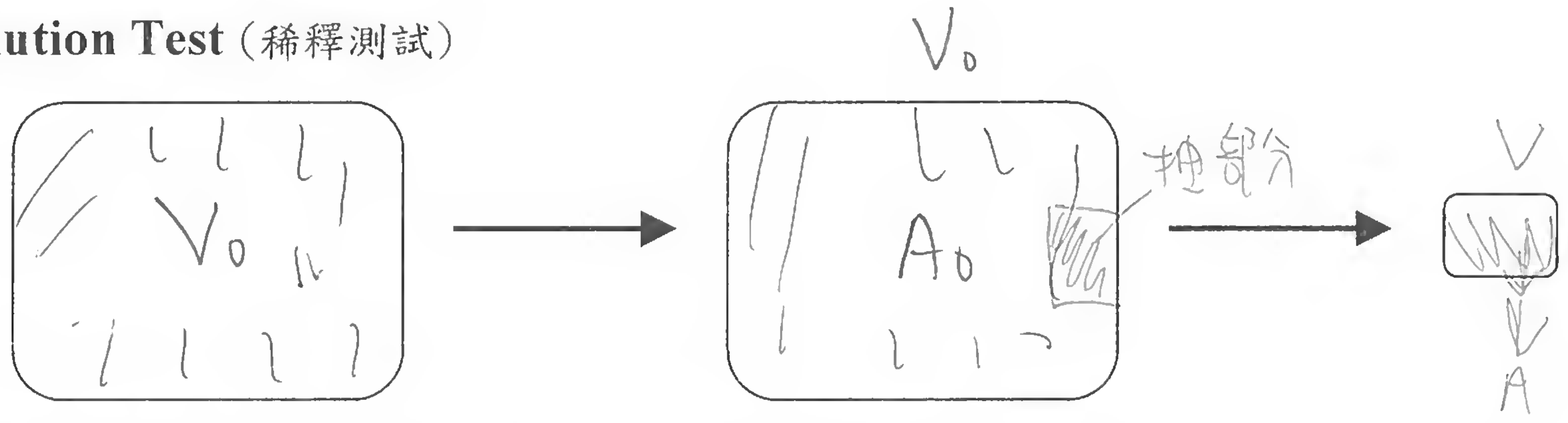


- Leaks in underground oil pipes can be detected by adding a small amount of radioactive source into the oil being pumped. Oil flows out from the leaks and radioactivity is detected on the ground around the leaks.
- Gamma-radiation should be used since its penetration power is great enough to penetrate through the ground.
- Choice of half-life :
  - The half-life should not be too short in order to have enough time for carrying the test.
  - The half-life should not be too long in order to cause less harmful effect to the environment.

Example : In order to detect cracks in an underground oil pipe, an engineer proposes adding a radioactive source to the oil. Which
(2004) of the following sources is most suitable ?

A. a γ source with a half-life of a few hours
B. a γ source with a half-life of several years
C. an α source with a half-life of a few hours
D. an α source with a half-life of several years

(vii) Dilution Test (稀釋測試)



✧ **The total volume of blood in a patient's body can be estimated by dilution test.**

✧ **Working principle :**

① A small amount of radioisotope is injected into the blood stream of the body.

② Allow some time for the radioisotope to circulate and dilute through the whole body.

③ A small amount of blood is then taken out from the patient's body and its activity is measured.

④ Since the activity is proportional to the volume of the blood, the total volume of the blood can then be found by $\dfrac{A}{A_o} = \dfrac{V}{V_o}$

✧ **Choice of the half life of the radioisotope :**

✲ The half-life should not be too short in order to have enough time for the source to dilute through the whole body.

✲ The half-life should not be too long in order to cause less harmful effect to the patient.

Example : A small volume of solution containing a radioactive isotope with an activity of 4400 disintegrations per minute is now
(1981) injected into the blood stream of a patient. After 20 hours the activity of 10 cm³ of blood becomes 2 disintegrations per minute. If the half-life of the isotope is 10 hours, estimate the volume of blood inside the person. (5 marks)

There are 2 half-lives in 20 hours $8 \to 4 \to 2.$ [1]

Original activities in 10 cm³ of blood $= 2 \times 2 \times 2$ [1]

$= 8$ [1]

$\therefore$ **Volume of blood** $= 10 \times \dfrac{4400}{8}$ $\qquad \dfrac{8}{4400} = \dfrac{10}{V_0}$ [1]

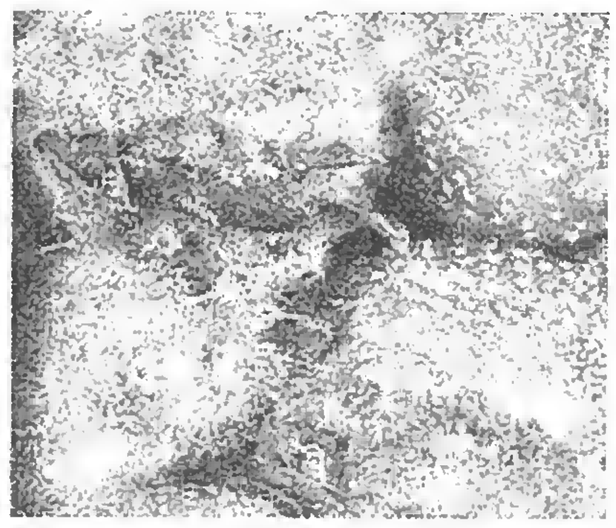
$= 5500 \text{ cm}^3$ [1]

(viii) Sterilization（消毒）

✧ **Hospital equipments（儀器）that cannot be boiled but carrying bacteria may be sterilized by using γ-radiation to kill the virus（病毒）and bacteria（細菌）.**

✧ **Food after packaged（包裝）can be sterilized by γ-radiation to kill bacteria inside.**

Strawberry with sterilization placed after 1 week



Strawberry without sterilization placed after 1 week

✧ **Gamma radiation is used since it has penetrating power large enough to reach every part of the equipments or food.**

✧ **The irradiated foods（輻射照過的食物）are not harmful to human bodies since γ radiation does not make the foods become radioactive.**

Example : Some fresh foods are exposed to γ radiations from radioactive isotopes for a short time so that the micro-organisms in (2006) the foods can be killed. Why are the irradiated foods not harmful to people who eat them ?

A. γ radiation is an electromagnetic wave.

B. γ radiation has a high penetrating power.

C. γ radiation does not have a high ionizing power.

D. γ radiation does not make the foods radioactive.

Example : Which of the following is/are application(s) of radioactivity ?

(2002) (1) to estimate the age of ancient remains C-14

(2) to kill bacteria in food γ

(3) to transmit signals over long distances radio waves

A. (2) only
B. (3) only
C. (1) & (2) only
D. (1) & (3) only

Example : Which of the following applications of radioactivity makes use of the fact that a radioactive nuclide has a constant (1999) half-life ?

A. Carbon-14 dating

B. Preservation of food

C. Smoke detectors

D. Thickness gauge

Example : Which of the following is **not** an application of radioactivity ?

(1997) A. Carbon-14 dating

B. Examination of foetuses (babies not yet born)

C. Killing cancer cells in human bodies

D. Sterilization of food

Example : The radioactive isotope of sodium, ${}^{24}_{11}\text{Na}$, decays by emitting a β particle to form a stable isotope of magnesium (Mg).

(1998) (a) Write down an equation for the decay. (2 marks)

$${}^{24}_{11}\text{Na} \longrightarrow {}^{24}_{12}\text{Mg} + {}^{0}_{-1}\beta$$ [2]

(b) Suppose you are given the following apparatus :

a GM counter, a sheet of paper and a 5 mm thick aluminium sheet.

Describe how you can demonstrate that ${}^{24}_{11}\text{Na}$ emits β particles and does not emit α particles. (4 marks)

The GM tube is held close from the source and its reading is noted. [1]

Insert a piece of paper between the GM tube and the source. [1]

The count rate would remain unaffected. This shows that the source does not emit α particles. [1]

Insert the aluminium sheet between the tube and the source.

The count rate would drop significantly. [1]

This shows that the source emits β particles.

(c) The half-life of ${}^{24}_{11}\text{Na}$ is 15 hours. A sample of ${}^{24}_{11}\text{Na}$ with an activity of 32×10^3 disintegrations per second is injected into the blood stream of a patient. After 45 hours, 6 cm^3 of blood is taken out from the patient's body and its activity is found to be 5 disintegrations per second.

(i) How many half-lives of ${}^{24}_{11}\text{Na}$ will have elapsed after 45 hours ? (1 mark)

Number of half-lives elapsed $= \dfrac{45}{15} = 3$ [1]

(ii) Estimate the volume of blood in the patient's body. (3 marks)

Initial activity of 6 cm³ of blood $= 5 \times 2^3 = 40$ [1]

$\therefore \quad \dfrac{V}{6} = \dfrac{32 \times 10^3}{40}$ [1]

$\therefore \quad V = 4800 \text{ cm}^3$ [1]

(iii) Suggest two reasons for using ${}^{24}_{11}\text{Na}$ as a medical tracer. (2 marks)

Any TWO of the following : [2]

* **The half-life is suitable for medical diagnosis.**
  (OR The half-life is short and the source will not retain inside the body for a long time.)
* **The penetrating power of β particles is strong enough to pass surface tissue of human body.**
* **The daughter nuclei Mg is stable and has no harmful effect.**
  (OR Sodium and magnesium have no harmful chemical effects on human body.)

DSE Physics M.C. - Section E		PE - M - RA2 / 01
Radioactivity II	Atomic Model	C.W.Sham

The following list of formulae may be found useful :

Law of radioactive decay	$N = N_0 e^{-kt}$
Half-life and decay constant	$t_{\frac{1}{2}} = \frac{\ln 2}{k}$
Activity and the number of undecayed nuclei	$A = kN$

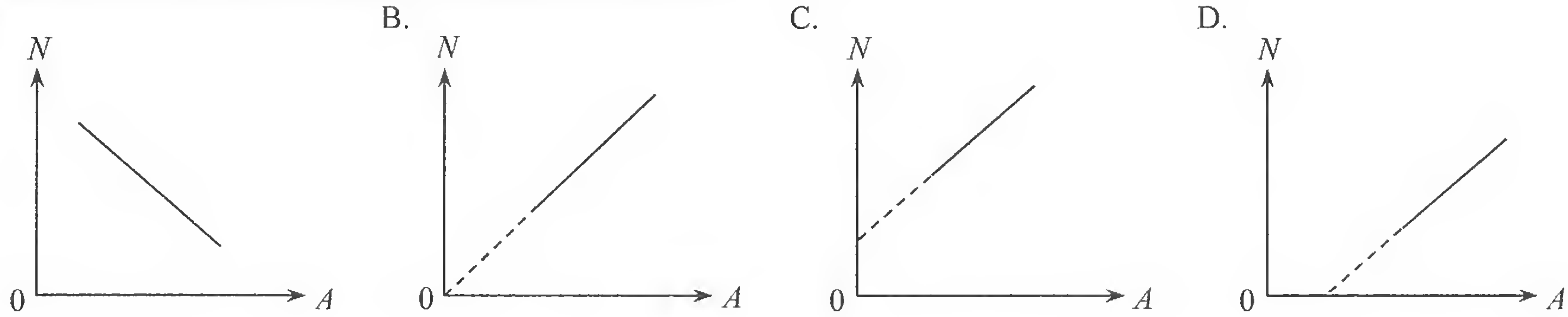
Part A :

The following questions marked with { } are the past DSE questions.

The number inside the brackets represents the year of the examination.

M1. Isotopes of an element have different mass number A and neutron number N. Which of the following $N - A$ plots correctly {12} shows the relationship of N and A for any given element ?

A. B. C. D.



M2. $^{238}_{92}\text{U}$ undergoes α - β - β - α decay and becomes a nuclide X. What are the atomic number and mass number of X ?

{13}

	atomic number	mass number
A.	90	230
B.	90	234
C.	88	230
D.	88	234

M3. Nucleus W decays to nucleus Z as shown below :
{14}

$$W \xrightarrow{\alpha} X \xrightarrow{\beta} Y \xrightarrow{\beta} Z$$

Which of the following statements is/are correct ?

(1) Nucleus X has 1 more proton than nucleus Y.
(2) Nucleus W has 2 more neutrons than nucleus X.
(3) W and Z are isotopes of the same element.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M4. A piece of ancient wood is dated using carbon-14 dating method. It registers a corrected count rate of 11.0 counts per minute {15} while a fresh wood sample cut from the same kind of trees gives a corrected count rate of 15.6 counts per minute. What is the approximate age of the wood found in the archaeological site ? Given : half-life of carbon-14 is 5730 years.

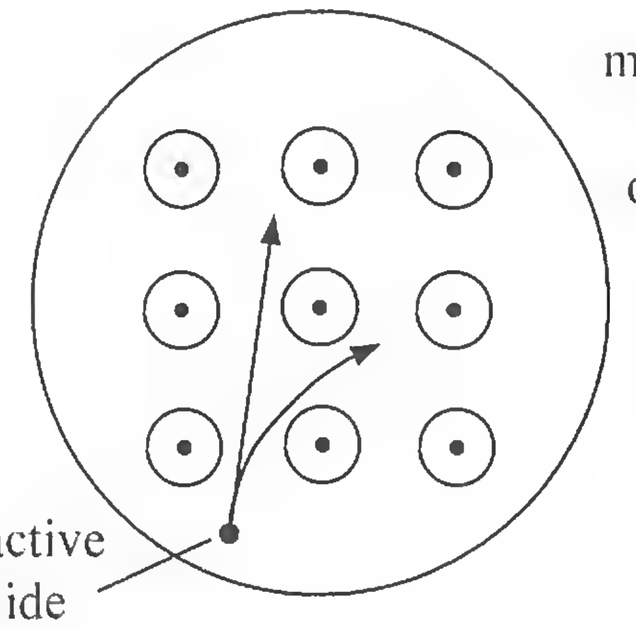
A. 890 years
B. 1300 years
C. 2000 years
D. 2900 years

Part B :

The following questions marked with ( ) are the past HKCE questions.

The number inside the brackets represents the year of the examination.

M5. A radioactive nuclide $^{A}_{Z}X$ undergoes radioactive decay inside a cloud chamber. The radiations emitted are subjected to a magnetic field and the resulting tracks are as shown in the figure. What are the atomic number and the mass number of the remaining nuclide ?
(80)



	Atomic Number	Mass Number
A.	$Z-2$	$A-4$
B.	$Z+1$	$A-4$
C.	$Z+1$	A
D.	$Z-1$	$A-4$

M6. The two isotopes $^{35}_{17}Cl$ and $^{37}_{17}Cl$ of chlorine have different
(80)
(1) numbers of protons
(2) number of neutrons
(3) chemical properties

A. (1) only
B. (2) only
C. (3) only
D. (1) & (2) only

M7. Which of the following statements concerning isotopes of an element is/are correct ?
(81)
(1) They have the same number of neutrons.
(2) They have the same chemical and physical properties.
(3) They have the same atomic number but different mass numbers.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M8. Which of the following represents an alpha decay ?
(81)
(1) $^{238}_{92}U \rightarrow {}^{234}_{90}Th$
(2) $^{215}_{85}At \rightarrow {}^{211}_{83}Bi$
(3) $^{210}_{81}Tl \rightarrow {}^{210}_{82}Pb$

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M9. The atomic structure of isotopes of the same element differ from each other by having different numbers of
(83)
A. electrons.
B. neutrons.
C. electrons and protons.
D. electrons and neutrons.

M10. An ancient piece of wood was tested for its age by carbon 14 dating method. The normal emission rate from 2 g of carbon
(84) from a living plant is 20 counts per minute. If the rate from 2 g of carbon from the wood is 5 counts per minute, and the half life of carbon 14 is 5700 years, what is the approximate age of the wood in years ? (Background radiation may be neglected.)

A. 5700×4
B. 5700×2
C. $5700 / 2$
D. $5700 / 4$

M11. During radioactive decay, ${}^{230}_{90}X$ becomes ${}^{226}_{90}Y$. Which of the following statements would be correct ?
(85) (1) The change would involve α decay only.
(2) One α particle and two β particles would be emitted.
(3) X and Y are two isotopes of the same element.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M12. A U-235 nucleus would change to Ac-227 through a series of decay :
(88) $${}^{235}_{92}\text{U} \xrightarrow{X} {}^{231}_{90}\text{Th} \xrightarrow{Y} {}^{231}_{91}\text{Pa} \xrightarrow{Z} {}^{227}_{89}\text{Ac}$$

What kind of particles are emitted at stages X, Y and Z in the radioactive decay chain shown above ?

	X	Y	Z
A.	α	α	β
B.	β	α	β
C.	β	β	α
D.	α	β	α

M13. The atomic number of Tin is 50 and its mass number is 112. Which of the following is an isotope of Tin ?
(88) A. ${}^{112}_{51}\text{X}$
B. ${}^{114}_{50}\text{X}$
C. ${}^{112}_{49}\text{X}$
D. ${}^{112}_{62}\text{X}$

M14. ${}^{235}_{92}\text{U}$ eventually decays to ${}^{207}_{82}\text{Pb}$.
(89) What is the number of α particles and β particles emitted during the decay ?

	α	β
A.	7	4
B.	7	10
C.	14	10
D.	28	4

M15. If the nucleus of an atom is represented by the symbol ${}^{214}_{83}\text{X}$, it means that this atom has
(90) (1) 131 protons in its nucleus.
(2) 83 electrons outside its nucleus.
(3) 214 neutrons in its nucleus.

A. (1) only
B. (2) only
C. (3) only
D. (1) & (2) only

M16. $^{238}_{92}U$ decays by emitting two α particles and two β particles. Which of the following represents the resulting nuclide ?

(92) A. $^{234}_{90}Th$

B. $^{234}_{92}U$

C. $^{232}_{88}Ra$

D. $^{230}_{90}Th$

M17. Which of the following symbols represents a neutron ?

(94) A. $^{0}_{0}n$

B. $^{1}_{0}n$

C. $^{0}_{1}n$

D. $^{1}_{1}n$

M18. A radioactive nuclide *W* decays to a nuclide *Z* by emitting one α-particle and two β-particles as shown below.

(95) $$W \xrightarrow{\beta} X \xrightarrow{\alpha} Y \xrightarrow{\beta} Z$$

Which of the following statements about nuclides *W*, *X*, *Y* and *Z* is/are correct ?

(1) *W* and *Z* are isotopes.

(2) *X* has the greatest atomic number.

(3) *Y* has the greatest mass number.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M19. Which of the following is **not** an application of radioactivity ?

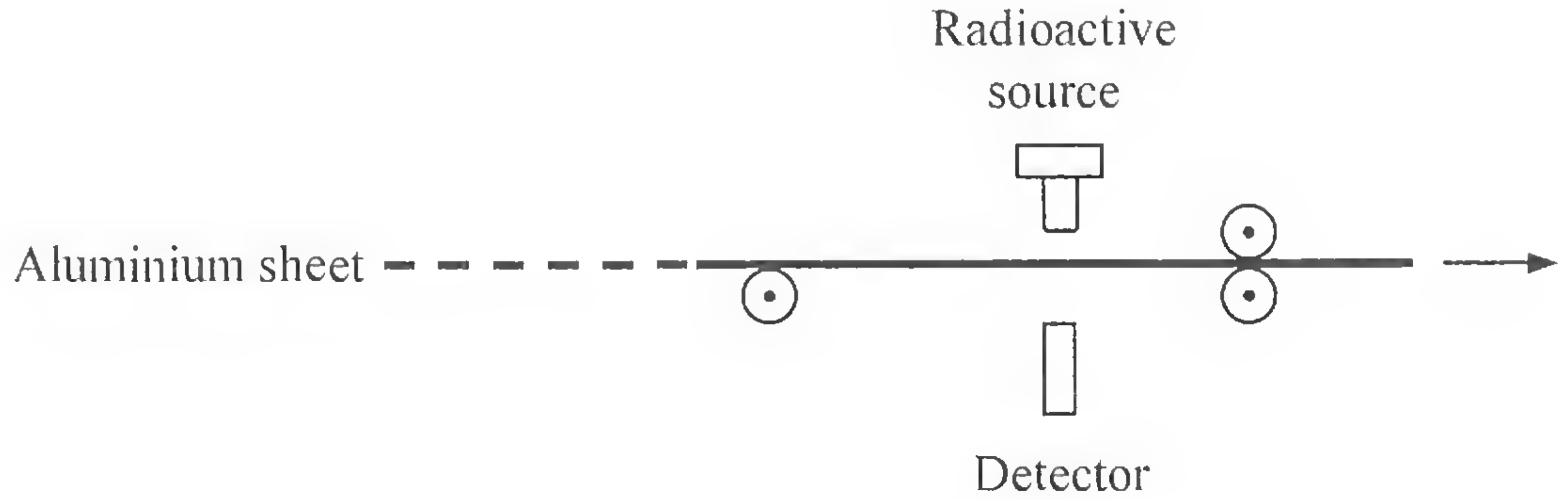
(97) A. Carbon-14 dating

B. Examination of foetuses (babies not yet born)

C. Killing cancer cells in human bodies

D. Sterilization of food

M20.
(98)



In a factory producing aluminium sheets of 1 mm thickness, a thickness gauge is used to monitor the thickness of aluminium sheets. Which of the following states the correct radioactive source to be used in the thickness gauge and the reason behind ?

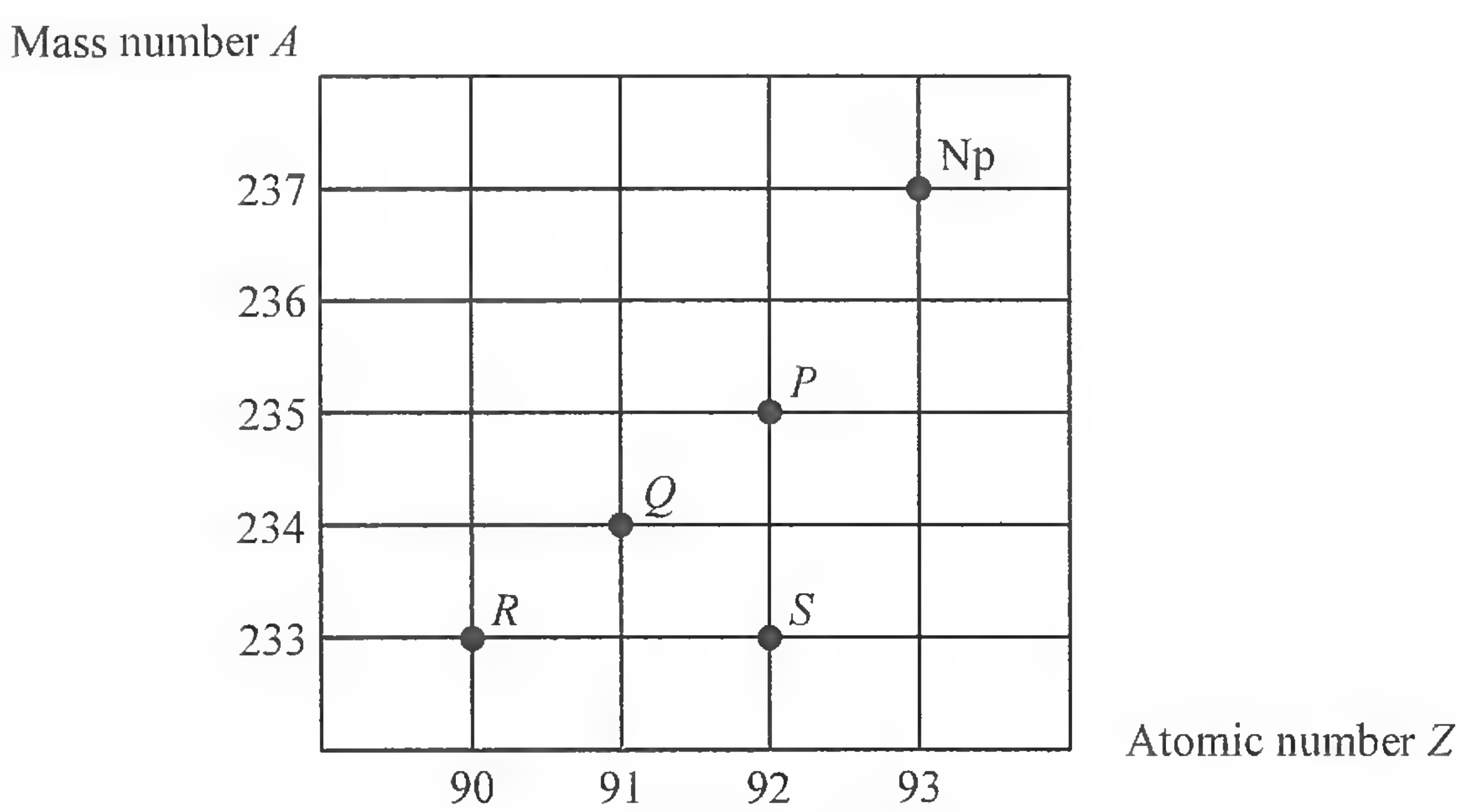
	Source	Reason
A.	α	The amount of α particles passing through aluminium depends on its thickness.
B.	β	The amount of β particles passing through aluminium depends on its thickness.
C.	β	β particles are less harmful to human beings.
D.	γ	γ radiation has the greatest penetrating power.

M21. A nucleus X emits a beta particle to form a daughter nucleus Y. Which of the following statements is/are correct ?
(98)
(1) X and Y have the same number of neutrons.
(2) The number of protons in X is greater than that in Y by 1.
(3) The total numbers of neutrons and protons in X and Y are equal.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M22. Which of the following applications of radioactivity makes use of the fact that a radioactive nuclide has a constant half-life ?
(99)
A. Carbon-14 dating
B. Preservation of food
C. Smoke detectors
D. Thickness gauge

M23.
(99)



The above diagram shows the mass number A and atomic number Z of a few nuclides. The isotope of neptunium (Np) shown decays by emitting an α particle and then a β particle.

Which of the following represents the resulting nuclide ?

A. P
B. Q
C. R
D. S

M24. The below shows part of a radioactive series.
(01)

$$P \xrightarrow{\alpha} Q \xrightarrow{\beta} R \xrightarrow{\beta} S$$

Which of the following nuclei are isotopes of the same element ?

A. P and Q
B. P and R
C. P and S
D. Q and S

M25. Radium ($^{226}_{88}\text{Ra}$) decays by emitting an α particle to form a product nucleus X. Which of the following shows the correct
(01) equation for this decay ?

A. $^{226}_{88}\text{Ra} + \alpha \longrightarrow {}^{230}_{90}\text{X}$

B. $^{226}_{88}\text{Ra} \longrightarrow {}^{224}_{84}\text{X} + \alpha$

C. $^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{X} + \alpha$

D. $^{226}_{88}\text{Ra} \longrightarrow {}^{226}_{89}\text{X} + \alpha$

M26. Which of the following is/are application(s) of radioactivity ?
(02)
(1) to estimate the age of ancient remains
(2) to kill bacteria in food
(3) to transmit signals over long distances

A. (2) only
B. (3) only
C. (1) & (2) only
D. (1) & (3) only

M27. A radioactive isotope $^{234}_{90}\text{Th}$ undergoes a series of decay processes to form a daughter $^{206}_{82}\text{Pb}$. How many α-particles and
(02) β-particles have been emitted in this decay process ?

	No. of α-particles	**No. of β-particles**
A.	6	7
B.	7	6
C.	7	8
D.	8	7

M28. Which of the following are essential criteria in choosing radioactive sources as medical tracers in human bodies ?
(03)
(1) The sources should have a short half-life.
(2) The radiation emitted should have a weak ionizing power.
(3) The radiation emitted should not be deflected by an electric field.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M29. In order to detect cracks in an underground oil pipe, an engineer proposes adding a radioactive source to the oil. Which of
(04) the following sources is most suitable ?

A. a γ source with a half-life of a few hours
B. a γ source with a half-life of several years
C. an α source with a half-life of a few hours
D. an α source with a half-life of several years

M30. A thorium nucleus ($^{234}_{90}\text{Th}$) decays by emitting a β particle to form a daughter nucleus X. Which of the following equations
(05) represents this decay ?

A. $^{234}_{90}\text{Th} \longrightarrow {}^{230}_{88}X + \beta$

B. $^{234}_{90}\text{Th} \longrightarrow {}^{234}_{89}X + \beta$

C. $^{234}_{90}\text{Th} \longrightarrow {}^{233}_{90}X + \beta$

D. $^{234}_{90}\text{Th} \longrightarrow {}^{234}_{91}X + \beta$

M31.
(06)

$$X \xrightarrow{\alpha} Y \xrightarrow{\beta} Z$$

$$P \xrightarrow{\beta} Q \xrightarrow{\beta} R \xrightarrow{\alpha} S$$

In the above two decay series, P and Y are two isotopes. Which of the following pairs of nuclides are isotopes to each other ?

(1) X and R

(2) Y and S

(3) Z and Q

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M32. (06) Some fresh foods are exposed to γ radiations from radioactive isotopes for a short time so that the micro-organisms in the foods can be killed. Why are the irradiated foods not harmful to people who eat them ?

A. γ radiation is an electromagnetic wave.

B. γ radiation has a high penetrating power.

C. γ radiation does not have a high ionizing power.

D. γ radiation does not make the foods radioactive.

M33. (07) In the upper atmosphere, neutrons are produced by the action of cosmic rays. These neutrons interact with nitrogen nuclei as shown in the following reaction:

$${}^{1}_{0}\mathrm{n} + {}^{14}_{7}\mathrm{N} \rightarrow X + {}^{1}_{1}\mathrm{H}$$

Element X will then emit a β particle.

The nuclear reaction is as follows : $X \rightarrow Y + {}^{0}_{-1}\beta$. What is the final product Y ?

A. ${}^{14}_{6}\mathrm{C}$

B. ${}^{13}_{6}\mathrm{C}$

C. ${}^{14}_{7}\mathrm{N}$

D. ${}^{13}_{7}\mathrm{N}$

M34.
(09)

$$X \xrightarrow{\alpha} Y \xrightarrow{\beta} Z$$

The above shows part of a decay series. Which of the following deductions is/are correct ?

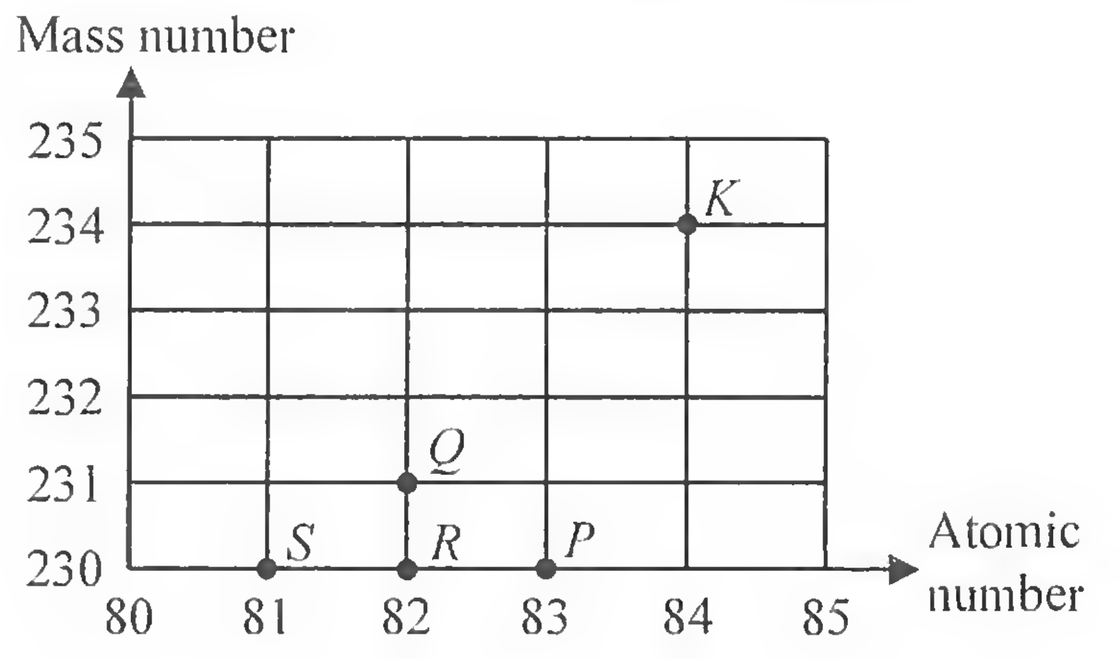
(1) X and Z are isotopes of the same element.

(2) X has two more neutrons than Z.

(3) Z has one more proton than Y.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M35. The diagram shows the mass number and atomic number of a
(10) radioactive nuclide K. After undergoing the following decays, it becomes Z.



$$K \xrightarrow{\alpha} X \xrightarrow{\beta} Y \xrightarrow{\gamma} Z$$

Which of the following nuclides represents Z ?

A. P
B. Q
C. R
D. S

M36. A $^{238}_{92}\text{U}$ nuclide undergoes a certain number of α and β decays and becomes $^{210}_{82}\text{Pb}$. Find the number of β particles emitted.

(11) A. 2
B. 3
C. 4
D. 5

Part C :

The following questions marked with [ ] are the past HKAL questions.

The number inside the brackets represents the year of the examination.

M37. A stationary radioactive nucleus of mass N units emits an alpha particle of mass 4 units, leaving a residual nucleus of mass
[81] $(N - 4)$ units. The ratio of the kinetic energy of the alpha particle to the kinetic energy of the residual nucleus is

A. $(N - 4)/4$
B. $N^2/(N - 4)^2$
C. $(N - 4)^2/N$
D. $(N - 4)^2/4^2$

M38. A stationary uranium-238 nucleus undergoes α-decay. What is the ratio of the kinetic energy of the daughter nucleus to that
[94] of the α-particle ?

A. 238 : 4
B. 4 : 238
C. 234 : 4
D. 4 : 234

M39. $^{226}_{88}\text{Ra}$ decays to $^{222}_{86}\text{Rn}$ with a half-life of 1600 years. Which of the following statements is/are correct ?

[95] (1) α particle is produced in the decay.
(2) All $^{226}_{88}\text{Ra}$ has decayed after 3200 years.
(3) The half-life of $^{226}_{88}\text{Ra}$ can be shortened by heating.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M40. $^{226}_{88}\text{Ra}$ is one of the nuclides in the uranium decay series. If the stable end-product of this series is $^{206}_{82}\text{Pb}$, the number of
[97] β-particles emitted between the $^{226}_{88}\text{Ra}$ stage and the end of the series is

A. 4

B. 6

C. 10

D. 14

M41. In β-decay a neutron inside the nucleus changes into a proton and an electron is emitted as a β-particle. Radioactive nuclide
[09] plutonium $^{244}_{94}\text{Pu}$ becomes lead $^{208}_{82}\text{Pb}$ after a series of α- and β-decays. Throughout the whole process, how many neutrons inside a $^{244}_{94}\text{Pu}$ nucleus have undergone such change ?

A. 3

B. 6

C. 9

D. 12

Answers

1. D	11. D	21. B	31. D	41. B
2. A	12. D	22. A	32. D	
3. D	13. B	23. D	33. C	
4. D	14. A	24. C	34. B	
5. A	15. B	25. C	35. A	
6. B	16. D	26. C	36. C	
7. B	17. B	27. B	37. A	
8. C	18. C	28. A	38. D	
9. B	19. B	29. A	39. A	
10. B	20. B	30. D	40. A	

Solution

1. D

Let Z be the atomic number, which is equal to the number of protons.

$A = Z + N \qquad \therefore N = A - Z$

Compared with $y = mx + c$, the graph is a straight line with slope +1 and with a negative y-intercept.

2. A

Atomic number of $X = 92 - 2 + 1 + 1 - 2 = 90$

Mass number of $X = 238 - 4 - 0 - 0 - 4 = 230$

3. D

$$^{100}_{50}W \xrightarrow{\alpha} {}^{96}_{48}X \xrightarrow{\beta} {}^{96}_{49}Y \xrightarrow{\beta} {}^{96}_{50}Z$$

Assume that the atomic mass and atomic number of W is 100 and 50 respectively.

× (1) Nucleus X should have 1 less proton than nucleus Y.

✓ (2) Nucleus W has 2 more neutrons and 2 more protons than nucleus X.

✓ (3) Since W and Z have the same number of protons, they are isotopes of the same element.

4. D

Method ① : $C = C_o \left(\frac{1}{2}\right)^{t/t_{1/2}}$

$\therefore (11.0) = (15.6)\left(\frac{1}{2}\right)^{t/5730} \qquad \therefore \log\left(\frac{11.0}{15.6}\right) = \log\left(\frac{1}{2}\right) \times \frac{t}{5730} \qquad \therefore t = 2888 \approx 2900$ years

Method ② : $k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{5730} = 1.21 \times 10^{-4}\ \text{year}^{-1}$

By $C = C_o e^{-kt} \qquad \therefore (11.0) = (15.6)\, e^{-(1.21\times10^{-4})\cdot t} \qquad \therefore t = 2887 \approx 2900$ years

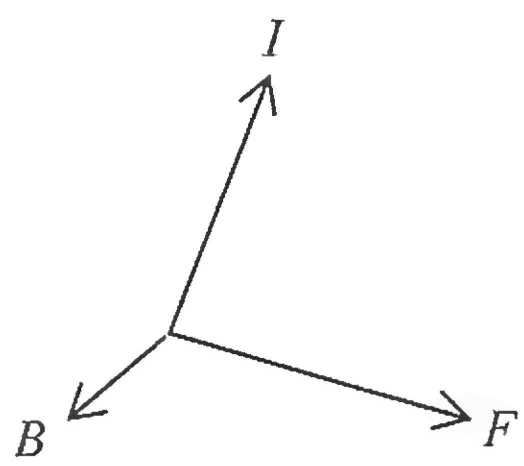
5. A

The magnetic field is directed out of paper.

The magnetic force is towards the right.

By using Left-hand rule, the direction of current is upwards, that is same as the direction of motion.

Thus the radiation carries (+) charge, it must be α-particle.



$\therefore\ {}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\mathrm{He}$

6. B

× (1) Both have 17 protons.

✓ (2) No. of neutrons in ${}^{35}_{17}\mathrm{Cl} = 35 - 17 = 18$; No. of neutrons in ${}^{37}_{17}\mathrm{Cl} = 37 - 17 = 20$

× (3) Isotopes have identical chemical properties.

7. B

× (1) Isotopes have different number of neutrons but have same number of protons.

× (2) Different mass number represents different physical properties.

✓ (3) This is the definition of isotopes.

8. C

✓ (1) ${}^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$

✓ (2) ${}^{215}_{85}\mathrm{At} \rightarrow {}^{211}_{83}\mathrm{Bi} + {}^{4}_{2}\mathrm{He}$

× (3) ${}^{210}_{83}\mathrm{Tl} \rightarrow {}^{210}_{82}\mathrm{Pb} + {}^{0}_{1}X$

9. B

Isotopes have different number of neutrons but have same number of protons, so as the electrons.

10. B

$20 \xrightarrow{\text{5700 years}} 10 \xrightarrow{\text{5700 years}} 5$

$\therefore$ Age of the wood $= 5700 \times 2$

11. D

× (1) ${}^{230}_{90}X \rightarrow {}^{4}_{2}\mathrm{He} + {}^{226}_{88}A$; since the atomic number of Y is 90, there must be β-decay in the series.

✓ (2) ${}^{230}_{90}X \rightarrow {}^{4}_{2}\mathrm{He} + {}^{226}_{88}A \rightarrow {}^{0}_{-1}e + {}^{226}_{89}B \rightarrow {}^{0}_{-1}e + {}^{226}_{90}Y$

✓ (3) Both X and Y have the same atomic number 90.

12. D

Balancing the equation : ${}^{235}_{92}\mathrm{U} \xrightarrow{{}^{4}_{2}\mathrm{He}} {}^{231}_{90}\mathrm{Th} \xrightarrow{{}^{0}_{-1}e} {}^{231}_{91}\mathrm{Pa} \xrightarrow{{}^{4}_{2}\mathrm{He}} {}^{227}_{89}\mathrm{Ac}$

$X = \alpha$ $\qquad Y = \beta$ $\qquad Z = \alpha$.

13. B

Isotopes have different mass number but same atomic number, i.e. 50.

$\therefore$ ${}^{114}_{50}X$ and Tin have the same atomic number and thus they are the same element.

14. A

${}^{235}_{92}U \rightarrow {}^{207}_{82}Pb + x\,{}^{4}_{2}He + y\,{}^{0}_{-1}e$

Balancing the mass, $235 = 207 + 4x$ $\therefore$ $x = 7$

Balancing the charge, $92 = 82 + 2(7) + y(-1)$ $\therefore$ $y = 4$

15. B

× (1) number of protons = atomic number = 83

✓ (2) number of electrons = number of protons = 83

× (3) number of neutrons = mass number – atomic number = 214 – 83 = 131

16. D

${}^{238}_{92}U \rightarrow {}^{A}_{Z}X + 2\,{}^{4}_{2}He + 2\,{}^{0}_{-1}e$

Balancing the mass number : $238 = A + 2 \times 4$ $\therefore$ $A = 230$

Balancing the atomic number : $92 = Z + 2 \times 2 + 2 \times (-1)$ $\therefore$ $Z = 90$

17. B

Upper number = Mass number of neutron = 1

Lower number = Charge of neutron = 0

18. C

Assume the mass number of W is 100 and the atomic number of W is 50. (OR any two arbitrary values)

$${}^{100}_{50}W \xrightarrow{{}^{0}_{-1}e} {}^{100}_{51}X \xrightarrow{{}^{4}_{2}He} {}^{96}_{49}Y \xrightarrow{{}^{0}_{-1}e} {}^{96}_{50}Z$$

✓ (1) W and Z have the same atomic number, thus they are isotopes.

✓ (2) The atomic number of X is 51, which is the greatest among the above 4 nuclides.

× (3) The mass number of Y is 96, which is less than that of W and X, not the greatest.

19. B

✓ A. Carbon-14 dating makes use of the detection of β-radiation emitted by carbon for archaeological study

× B. Examination of fetuses makes use of ultrasound

✓ C. Killing cancer cells makes use of γ-rays

✓ D. Sterilization of food makes use of γ-rays

20. B

β particles are only partly absorbed by thin sheet of aluminium

$\therefore$ amount of β particles passing through depends on its thickness

$\therefore$ β can be used to check thickness of aluminium sheets

21. B

$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$

× (1) Number of neutron in $X = A - Z$; Number of neutron in $Y = A - (Z + 1)$

× (2) The number of protons in Y is greater than that in X by 1

✓ (3) Same mass number $\Rightarrow$ same total numbers of neutrons and protons

22. A

✓ A. Age of ancient findings can be found by C-14 that emit β radiation with a constant half-life

× B. Use γ-rays to kill bacteria and germs

× C. Use α-radiation to ionize the air

× D. Use β-radiation to check thickness of aluminium sheets

23. D

$^{237}_{93}\text{Np} \xrightarrow{^{4}_{2}\text{He}} {}^{233}_{91}X \xrightarrow{^{0}_{-1}e} {}^{233}_{92}S$

24. C

Assume the atomic number of P is Z

Atomic number of $Q = Z - 2$

Atomic number of $R = Z - 2 + 1 = Z - 1$

Atomic number of $S = Z - 2 + 1 + 1 = Z$

Thus, P and S have the same atomic number, they are isotopes of the same element.

25. C

$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{X} + {}^{4}_{2}\alpha$

26. C

✓ (1) carbon 14 dating is used to estimate the age of ancient remains

✓ (2) gamma rays are used to kill bacteria in food

× (3) microwaves are used to transmit signals over long distances

27. B

Balancing the equation : $^{234}_{90}\text{Th} \longrightarrow {}^{206}_{82}\text{Pb} + x\,{}^{4}_{2}\alpha + y\,{}^{0}_{-1}\beta$

$234 = 206 + 4x$ $\therefore$ $x = 7$

$90 = 82 + 2(7) + (-1)y$ $\therefore$ $y = 6$

28. A

✓ (1) The sources should have a short half-life so as to reduce the harmful effect to human bodies

✓ (2) The radiation should have a weak ionizing power so that it can cause less harmful effect to human bodies

× (3) β-radiation, which can be deflected by an electric field, can be used as medical tracers.
Since human bodies do not have electric field, this is not a criterion in choosing medical tracers.

29. A

γ source should be used

since it has great penetrating power to pass through the pipe wall and the ground to be detected.

The half life should be short in order to reduce the harmful effect to the environment.

30. D

The symbol of β is ${}^{0}_{-1}\beta$.

Thus the mass number of X is unchanged and the atomic number of X should be 91.

31. D

Since P and Y are two isotopes, they must have the same atomic number but different mass number.

Assume the atomic number of P and Y are both equal to n.

$${}_{n+2}X \xrightarrow{{}^{4}_{2}\alpha} {}_{n}Y \xrightarrow{{}^{0}_{-1}\beta} {}_{n+1}Z$$

$${}_{n}P \xrightarrow{{}^{0}_{-1}\beta} {}_{n+1}Q \xrightarrow{{}^{0}_{-1}\beta} {}_{n+2}R \xrightarrow{{}^{4}_{2}\alpha} {}_{n}S$$

✓ (1) Both X and R have the same atomic number of $n + 2$.

✓ (2) Both Y and S have the same atomic number of n.

✓ (3) Both Z and Q have the same atomic number of $n + 1$.

32. D

After the foods have been exposed to γ radiations,

the foods will not become radioactive,

since there is no radioactive source in the foods.

33. C

The neutron interacts with nitrogen :

$${}^{1}_{0}\text{n} + {}^{14}_{7}\text{N} \rightarrow {}^{14}_{6}X + {}^{1}_{1}\text{H}$$

The equation for the nuclear reaction :

$${}^{14}_{6}X \rightarrow {}^{14}_{7}Y + {}^{0}_{-1}\beta$$

The final product Y is ${}^{14}_{7}\text{N}$

34. B

Assume the atomic number of X is 50 and the mass number of X is 100 :

$$^{100}_{50}X \xrightarrow{^4_2\alpha} {}^{96}_{48}Y \xrightarrow{^0_{-1}\beta} {}^{96}_{49}Z$$

× (1) Since the atomic numbers of X and Z are not equal, they are not isotopes of the same element.

× (2) The number of neutrons of X is 50 and the number of neutrons of Z is $96 - 49 = 47$
Thus X should have 3 more neutrons than Z.

✓ (3) The number of protons of Y is 48 and that of Z is 49, thus Z has one more proton than Y.

35. A

Mass number of K is 234 and atomic number of K is 84.

$$^{234}_{84}K \xrightarrow{^4_2\alpha} {}^{230}_{82}X \xrightarrow{^0_{-1}\beta} {}^{230}_{83}Y \xrightarrow{\gamma} {}^{230}_{83}Z$$

The final product is P which has the mass number of 230 and atomic number of 83.

36. C

$238 = 210 + 4\,\alpha$ $\quad\therefore\ \alpha = 7$

$92 = 82 + 2 \times 7 - \beta$ $\quad\therefore\ \beta = 4$

37. A

$$KE = \frac{1}{2} m v^2 = \frac{(m v)^2}{2m}$$

since the daughter nucleus and the α particle must have the same magnitude of momentum after the explosion

$$\therefore\ KE \propto \frac{1}{m}$$

$$\frac{KE_\alpha}{KE_{\text{nucleus}}} = \frac{m_{\text{nucleus}}}{m_\alpha} = \frac{N-4}{4}$$

38. D

$$KE = \frac{1}{2} m v^2 = \frac{(m v)^2}{2m}$$

since the daughter nucleus and the α particle must have the same magnitude of momentum after the explosion

$$\therefore\ KE \propto \frac{1}{m} \qquad \therefore\ \frac{KE_{\text{nucleus}}}{KE_\alpha} = \frac{m_\alpha}{m_{\text{nucleus}}} = \frac{4}{238-4} = \frac{4}{234}$$

39. A

✓ (1) Balancing the equation : $^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^4_2\mathrm{He}$.

× (2) It takes infinite time for all $^{226}_{88}\mathrm{Ra}$ to decay.

× (3) Nuclear change cannot be changed by the surrounding temperature.

40. A

$$^{226}_{88}\text{Ra} \rightarrow {}^{206}_{82}\text{Pb} + x\,^{4}_{2}\text{He} + y\,^{0}_{-1}e$$

Balancing the mass number, $226 = 206 + 4x$ $\therefore\ x = 5$

Balancing the atomic number, $88 = 82 + 2(5) + y(-1)$ $\therefore\ y = 4$

$\therefore$ 4 β-particles are emitted.

41. B

Consider the mass number : $244 = 208 + a(4)$ $\therefore\ a = 9$

There are 9 alpha particles emitted in the series.

Consider the atomic number : $94 = 82 + 9 \times (2) + b(-1)$ $\therefore\ b = 6$

There are 6 beta particles emitted in the series.

As each emission of beta particle involves a decay of neutron, there are 6 neutrons having such change.

Use the following data wherever necessary :

Avogadro constant	$N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$

The following list of formulae may be found useful :

Law of radioactive decay	$N = N_0 e^{-kt}$
Half-life and decay constant	$t_{\frac{1}{2}} = \dfrac{\ln 2}{k}$
Activity and the number of undecayed nuclei	$A = kN$

Part A :

The following question marked with { } is the past DSE question.

The number inside the bracket represents the year of the examination.

Q1. {13} Carbon-14 dating can be used to identify the age of some objects which have the ^{14}C isotope, as it is radioactive and decays by emitting a β-particle. A piece of wood sample is examined using carbon-14 dating and its activity is 0.2 Bq. The half-life of ^{14}C is 5730 years. Given : 1 year = 3.16×10^7 s

(a) Calculate the decay constant of ^{14}C in s^{-1}. Hence find the number of ^{14}C nuclei in this wood sample. (3 marks)

Assume that living organisms contain a constant proportion of carbon-14 in the ratio of ^{14}C / ^{12}C = 1.3×10^{-12} during its life time via intake of carbon dioxide (CO_2) from the atmosphere.

(b) The carbon content of this wood sample is found to contain a total of 1×10^{23} carbon nuclei. Estimate the number of ^{14}C nuclei in the sample originally when it died. (1 mark)

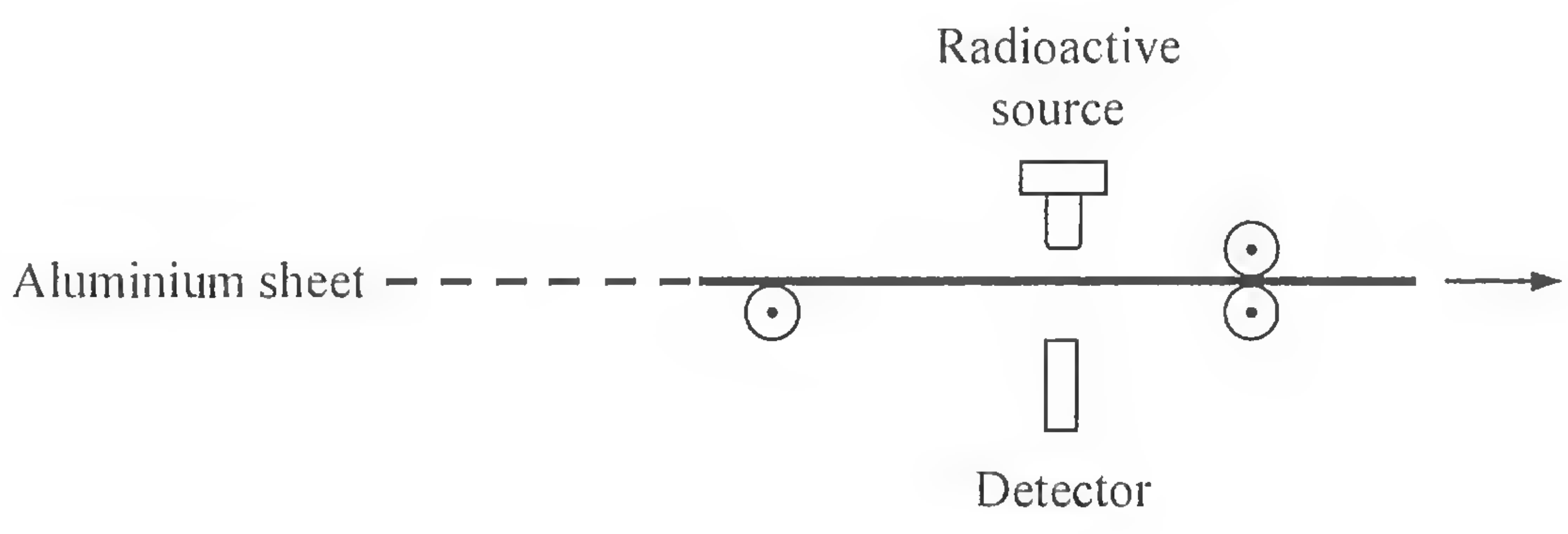
(c) Estimate the age of this wood sample in years using the results found in (a) and (b). (2 marks)

Part B :

The following questions marked with ( ) are the past HKCE questions.

The number inside the brackets represents the year of the examination.

Q2. (80) (a) A factory aims at producing aluminium sheets of 1 mm thickness. A radioactive source and a detector is used to monitor the thickness of the aluminium sheet manufactured as shown in the figure below.



(i) State what type of source (α, β or γ) should be used. (2 marks)

(ii) Explain briefly why the other two types of source are not used. (3 marks)

(b) Give TWO other applications of radioactivity. (2 marks)

Q3. (a)
(81)

Figure 1

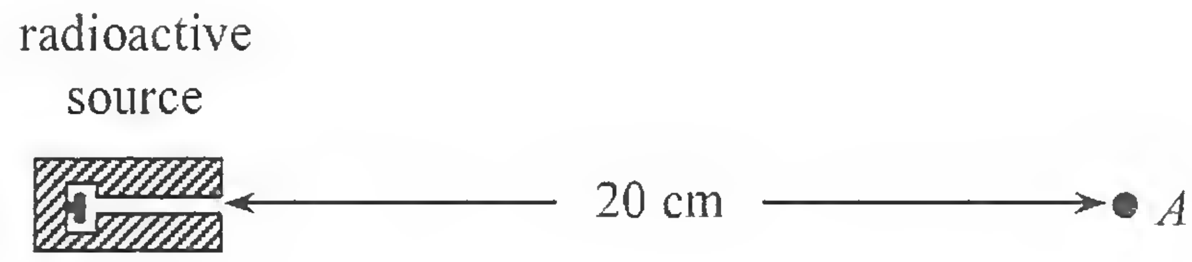
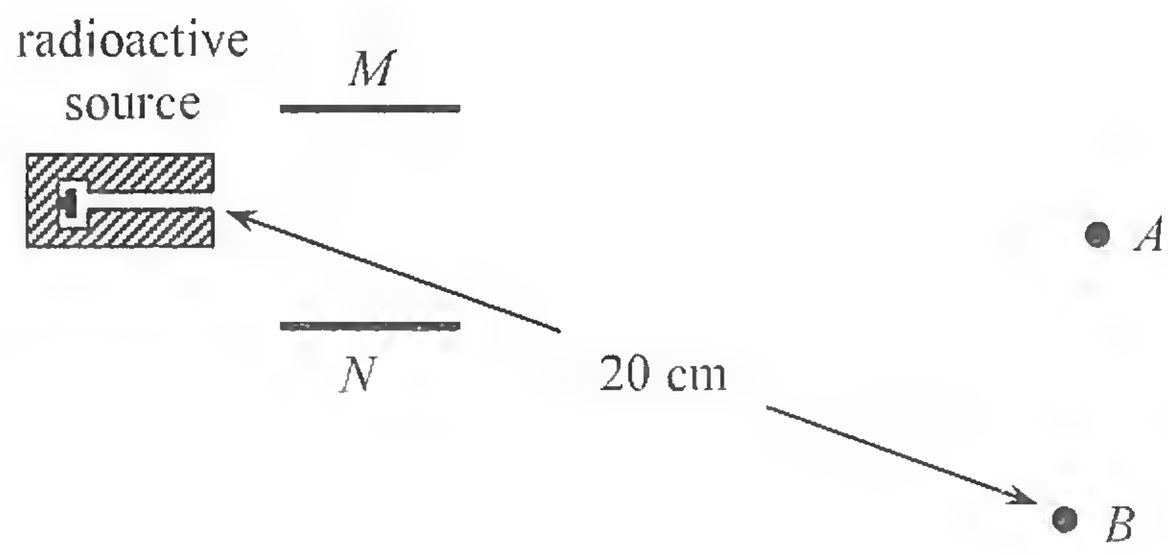


Figure 2



$^{238}_{92}\text{U}$ is a radioactive source giving α, β and γ radiations.

(i) If $^{238}_{92}\text{U}$ decays by emitting four α-particles and two β-particles, what will be the atomic number and mass number of the resulting nucleus ? (6 marks)

(ii) A GM counter is placed at A as shown in the Figure 1 about 20 cm from the source. What types of radiation can be received by the counter at A ? (2 marks)

(iii) An electric field is applied across the metal plates M and N as shown in the Figure 2 so that M is connected to the positive terminal and N is connected to the negative terminal of a voltage supply. The GM counter is now moved to B about 20 cm from the source. Describe and explain what happens to the count-rate. (2 marks)

(b) A small volume of solution containing a radioactive isotope with an activity of 4400 disintegrations per minute is now injected into the blood stream of a patient. After 20 hours the activity of 10 cm^3 of blood becomes 2 disintegrations per minute. If the half-life of the isotope is 10 hours, estimate the volume of blood inside the person. (5 marks)

(c) If an α-particle is emitted from an atom of $^{224}_{88}\text{Ra}$ during the decay process, what will be the mass number and the atomic number of the daughter atom ? (2 marks)

Q4. (a) What are the mass numbers of

(82) (i) α-particles,

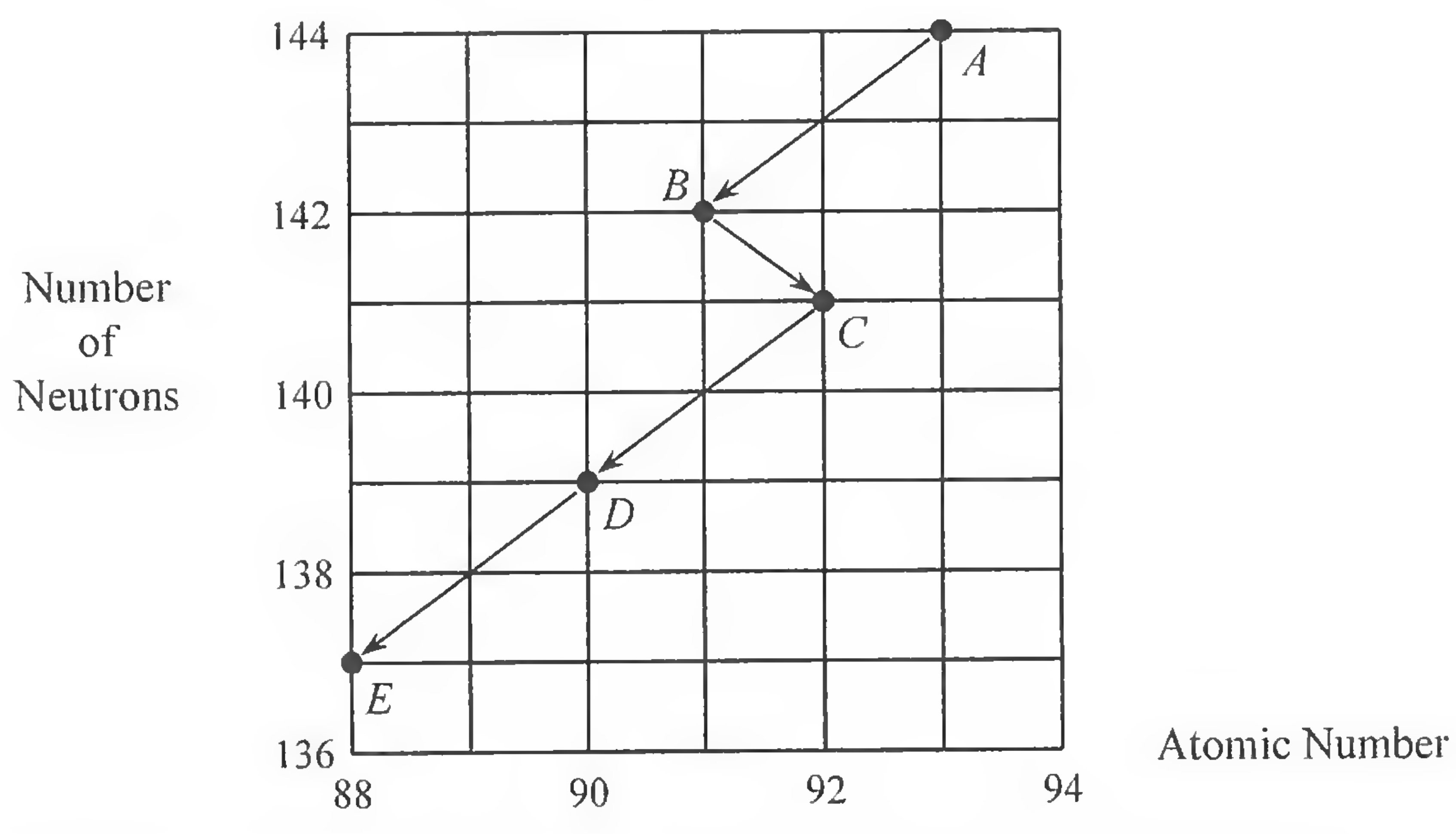
(ii) β-particles, and

(iii) neutrons ? (3 marks)

(b) The parent α source is $^{226}_{88}\text{Ra}$. If the daughter nucleus of Ra after α decay is X, write down the equation of the α-decay. (3 marks)

(c) If $^{234}_{91}X$ decays by emitting one α particle and one β particle to form a stable product nucleus Y, what will be the atomic number and mass number of Y ? (2 marks)

(d)

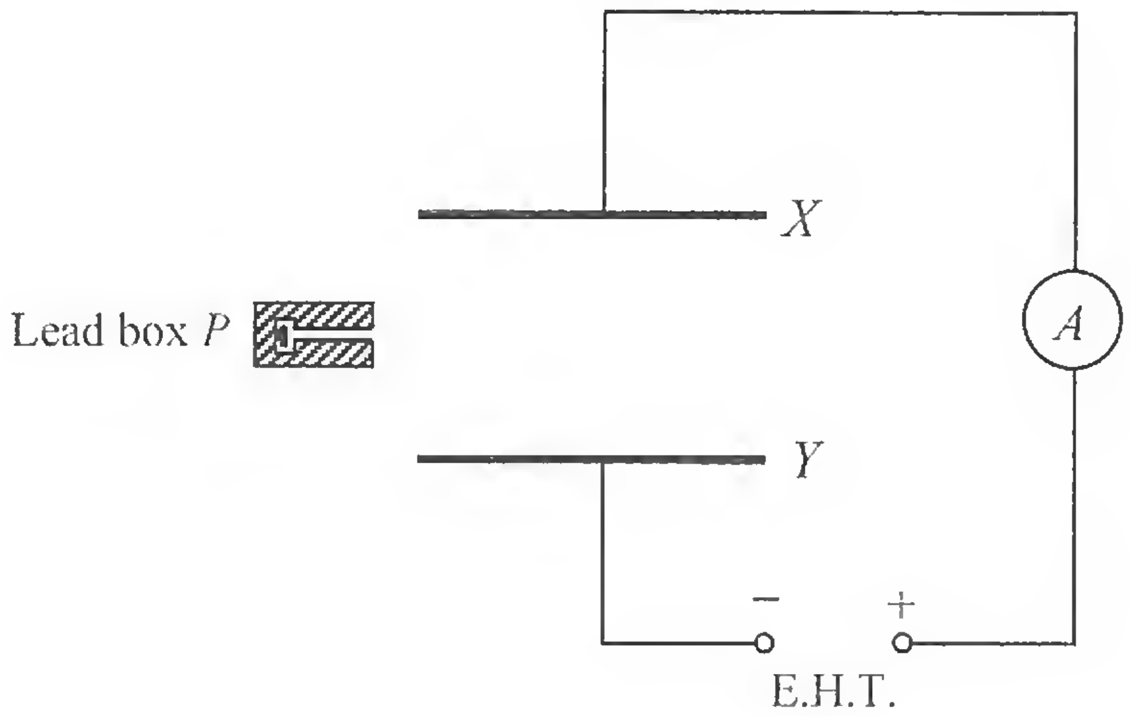


The above figure shows a radioactive decay series : $A \rightarrow B \rightarrow C \rightarrow D \rightarrow E$

(i) State what particles are emitted at each stage. (4 marks)

(ii) What is the mass number of C ? (1 mark)

Q5. (91) (a) Two metal plates X and Y are connected to a sensitive ammeter and an extra high tension supply (E.H.T.). A lead box P is placed near the metal plates as shown in the below figure.



(i) Sketch the electric field pattern between X and Y. The direction of the field should be shown. (2 marks)

(ii) If a radioactive source emitting α particles is placed in P, the ammeter shows that a current is flowing. Explain why there is a current. (2 marks)

____

____

(iii) Explain what happens to the ammeter reading if the source in (ii) is replaced by one emitting γ rays ? (2 marks)

____

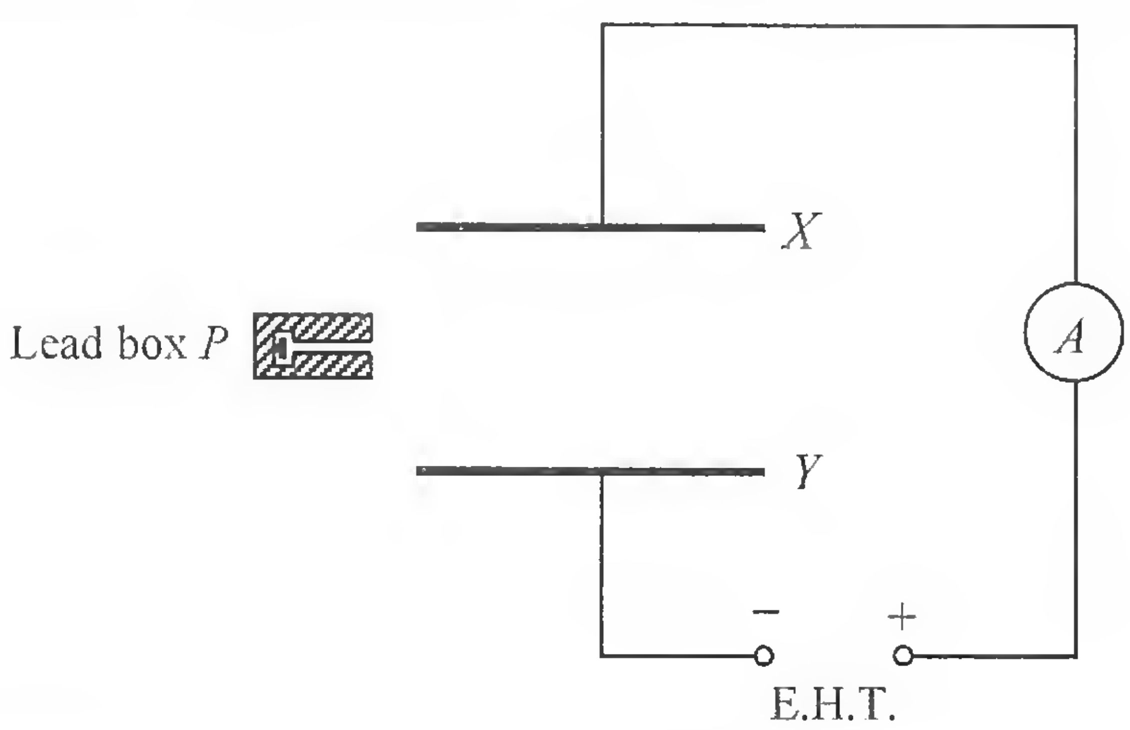
____

(iv) Suppose now a radioactive source $^{234}_{91}\text{Pa}$ is placed in P. $^{234}_{91}\text{Pa}$ decays by emitting a β particles and γ rays to form a daughter nucleus U.

(1) Write down an equation for the decay. (1 mark)

____

(2) On the below figure, sketch and label the paths of the radiation emitted by the source. (2 marks)



(b) Leaks in underground oil pipes can be detected by adding a small amount of radioactive source into the oil being pumped. Oil flows out from the leaks and radioactivity is detected on the ground around the leaks.

(i) Which type of source (α, β or γ) is suitable ? Explain briefly. (2 marks)

____

____

(ii) Two sources emitting the suitable type of radiation of half-lives 50 years and 10 hours are available. Which one should be used ? Explain briefly. (3 marks)

____

____

Q6. In an experiment to measure the half-life of a radioactive isotope of sodium in a place where the background count rate is
(93) 100 counts per minute, the following result is obtained :

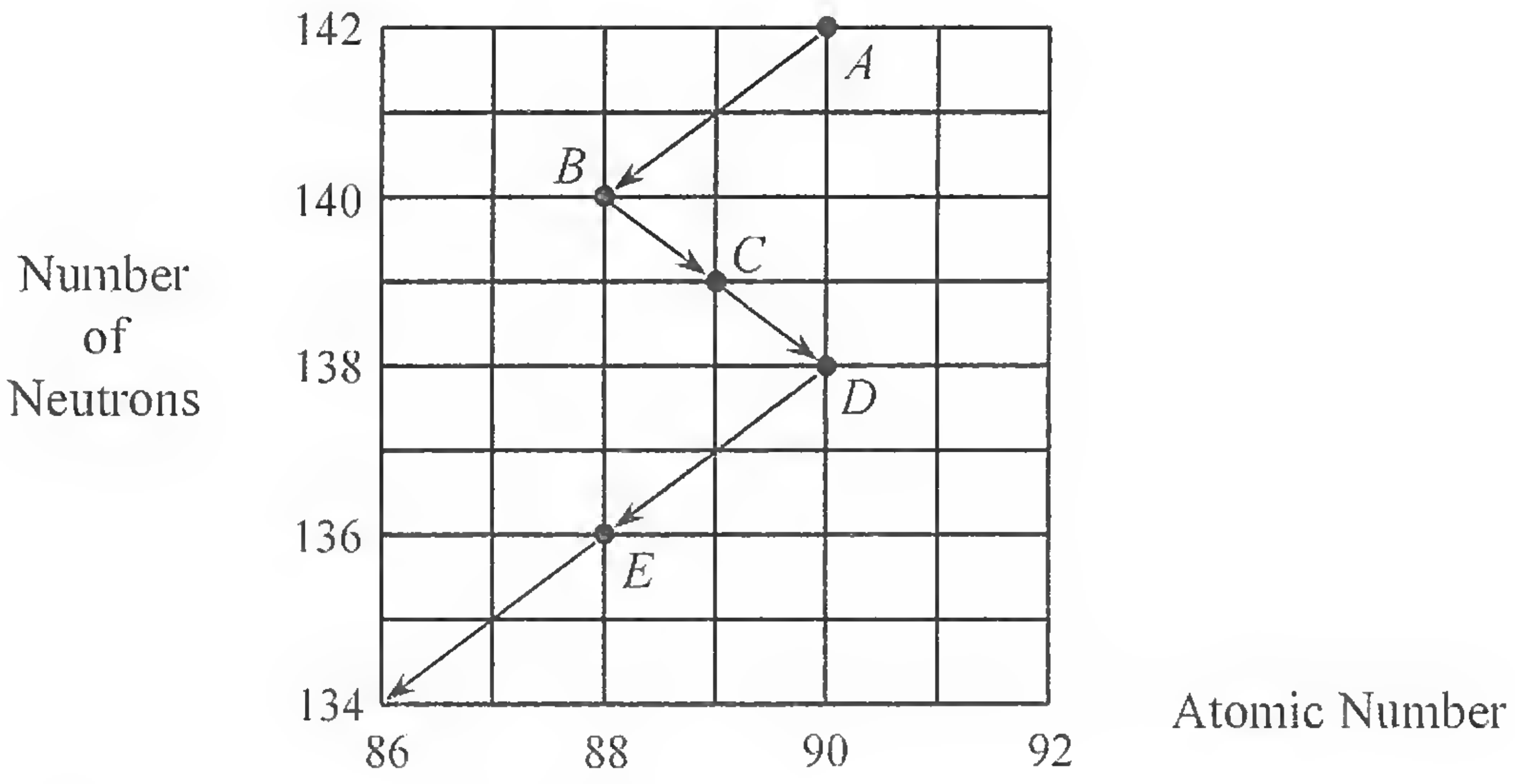
Time / hour	0	20	40	60	80	100	120
Total count rate/counts per min.	1100	498	259	161	125	110	104

(a) Suggest TWO major sources of background radiation. (2 marks)

(b) Plot the graph of the CORRECTED count rate against time on graph paper. Hence find the half-life of the isotope. (6 marks)

(c) By considering its half-life, state whether the isotope is suitable to be used for injecting into a patient's vein so as to investigate his blood circulation. Give your reason. (3 marks)

Q7. The below figure shows part of a decay series.
(94)



(a) From the figure, name the particle which is emitted in each of the following changes :

(i) $A \rightarrow B$

(ii) $B \rightarrow C$ (2 marks)

(b) State two nuclides in the series which are isotopes of each other. (1 mark)

(c) The final stable nuclide of the series is X, whose atomic number is 82 and the number of neutrons is 126.

(i) Find the mass numbers of A and X. (2 marks)

(ii) Find the total number of α particles emitted from A to X. (2 marks)

(d) Some of the nuclides in the figure also emit γ-radiation when they decay. However, it is impossible to identify these nuclides from the figure. Explain briefly. (2 marks)

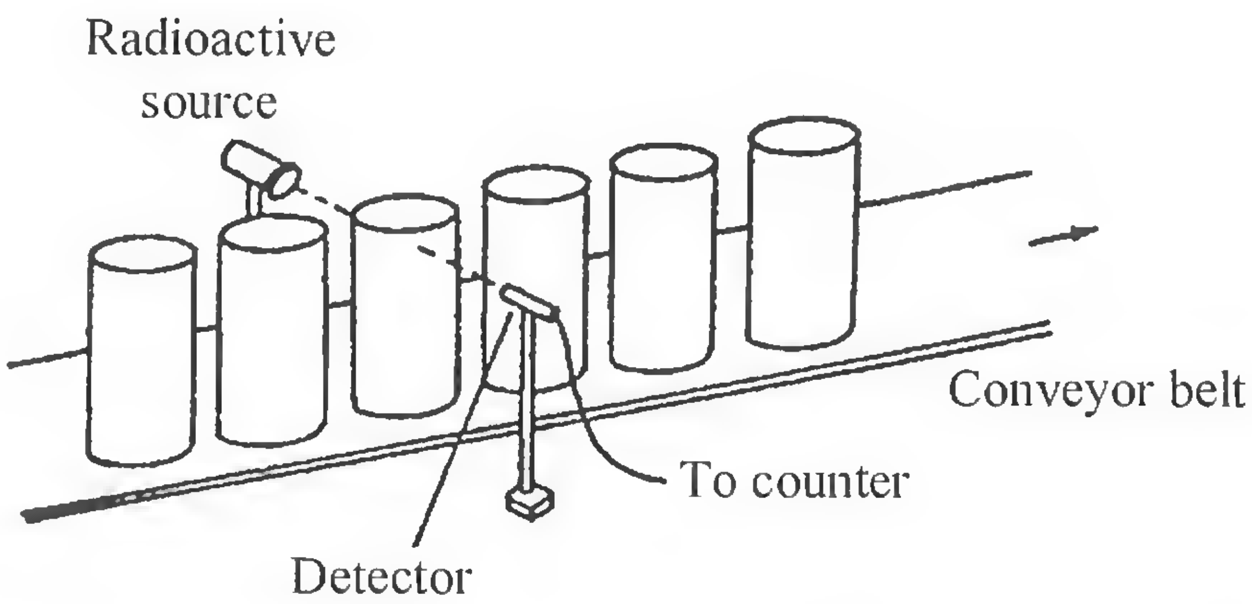
(e) A GM counter is placed 20 cm from a radioactive source which undergoes the decay as shown in the above figure. The corrected count rates obtained in three consecutive minutes are 1027, 1011 and 1018 counts per minute respectively.

(i) What type(s) of radiation emitted by the source can reach the counter ? Explain briefly. (2 marks)

(ii) Explain what is meant by a CORRECTED count rate. (2 marks)

(iii) Explain briefly why the three readings differ from each other. (2 marks)

Q8.
(96)



A factory produces detergent contained in plastic bottles. The following method is used to monitor the amount of detergent contained in each bottle : a radioactive source is placed on one side of the conveyor belt at the level to which the detergent is expected to fill and a detector is placed at the same level on the other side as shown in the figure above.

(a) Which type of radioactive source (α, β or γ) should be used ? Explain briefly why the other two types are not suitable. (3 marks)

(b) Suggest one suitable detector for the above system. (1 mark)

(c) Explain how the monitoring system can detect bottles of detergent that have not been filled up to the required level. (3 marks)

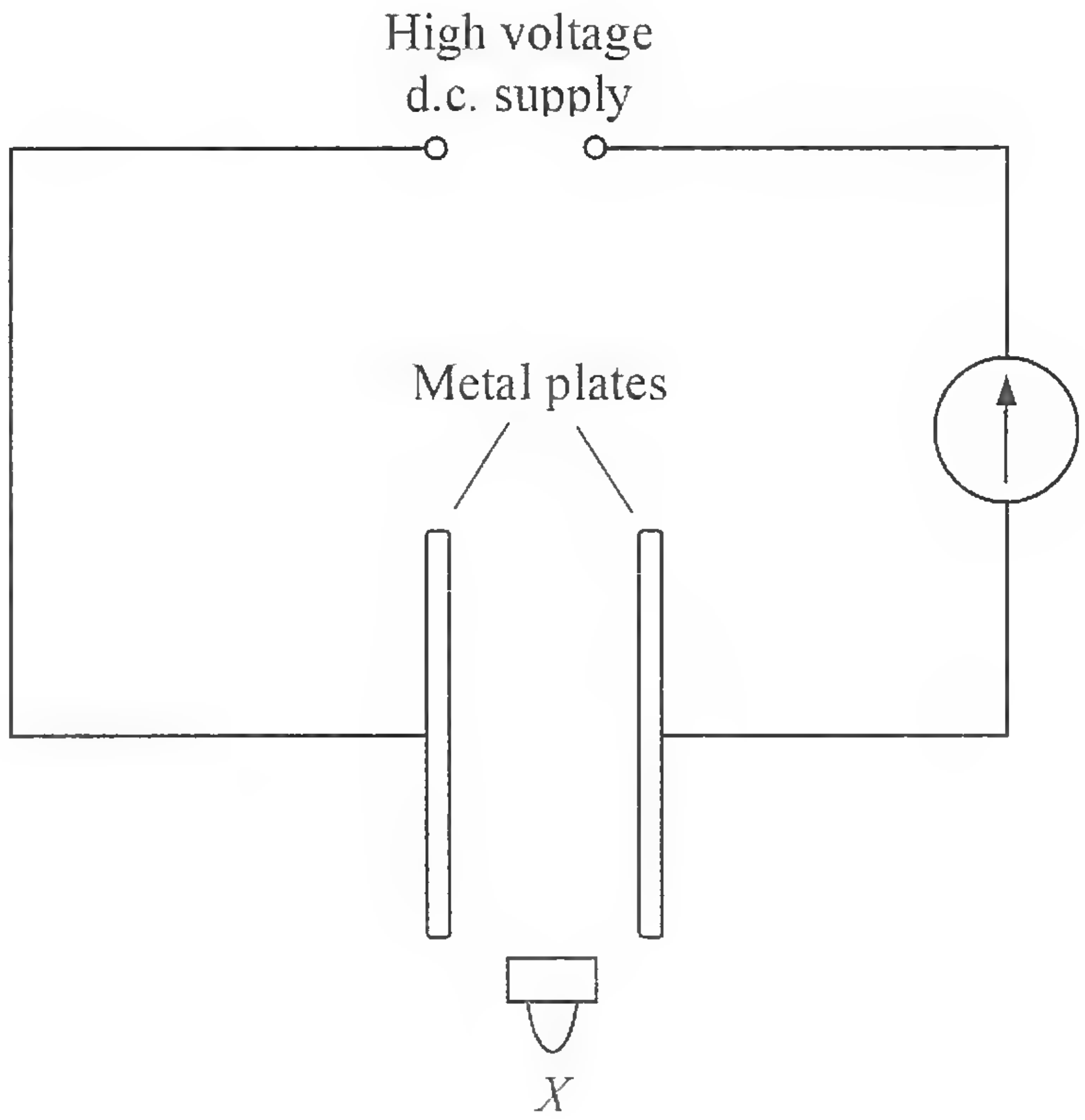
(d) Two sources emitting the suitable type of radiation of half-lives 10 minutes and 5 years are available.

(i) Explain what is meant by the half-life of a radioactive source. (2 marks)

(ii) Which source should be used ? Explain briefly. (3 marks)

(e) State two safety precautions that factory workers should take when handling radioactive sources. (2 marks)

Q9.
(97)



Two metal plates are connected to a high voltage d.c. supply and a galvanometer as shown in the Figure above. When a radioactive source X emitting α particles is placed very near the metal plates, the galvanometer shows that a current is flowing. When X is moved a small distance away from the two plates, the galvanometer reading quickly drops to zero.

(a) Explain why there is a current and why it is present only when X is very near the metal plates. (3 marks)

(b) ${}^{220}_{86}X$ decays by emitting an α particle to form a stable nucleus Y. Write down an equation for the decay. What is the neutron number of Y? (3 marks)

(c) How would the galvanometer reading be affected if X is replaced by a β source ? Explain briefly. (2 marks)

Q9. (d) X is placed very near the metal plates and the galvanometer reading is recorded every 30 seconds. The results obtained are shown below :

Time / s	0	30	60	90	120	150
Current / μA	72	48	32	22	15	10

(i) Plot a graph of current against time on graph paper. (4 marks)

(ii) Hence find the half-life of X.

(Note : You may assume that the activity of the source is directly proportional to the current.) (1 mark)

(e) Explain why X is **not** suitable for use as tracers. (1 mark)

Q10. The radioactive isotope of sodium, $^{24}_{11}\text{Na}$, decays by emitting a β particle to form a stable isotope of magnesium (Mg).
(98)

(a) Write down an equation for the decay. (2 marks)

(b) Suppose you are given the following apparatus :

a GM counter, a sheet of paper and a 5 mm thick aluminium sheet.

Describe how you can demonstrate that $^{24}_{11}\text{Na}$ emits β particles and does not emit α particles. (4 marks)

(c) The half-life of $^{24}_{11}\text{Na}$ is 15 hours. A sample of $^{24}_{11}\text{Na}$ with an activity of 32×10^3 disintegrations per second is injected into the blood stream of a patient. After 45 hours, 6 cm^3 of blood is taken out from the patient's body and its activity is found to be 5 disintegrations per second.

(i) How many half-lives of $^{24}_{11}\text{Na}$ will have elapsed after 45 hours ? (1 mark)

(ii) Estimate the volume of blood in the patient's body. (3 marks)

(iii) Suggest **two** reasons for using $^{24}_{11}\text{Na}$ in this dilution test. (2 marks)

(d) State an application of radioactive isotopes, other than tracers, in each of the following fields :

(i) Medicine (1 mark)

(ii) Industry (1 mark)

Q11. (a) X and Y are two radioactive nuclides with half lives of 12 hours and 2.6 years respectively. Both two nuclides decay by
(00) emitting a β particle to form stable product nuclides.

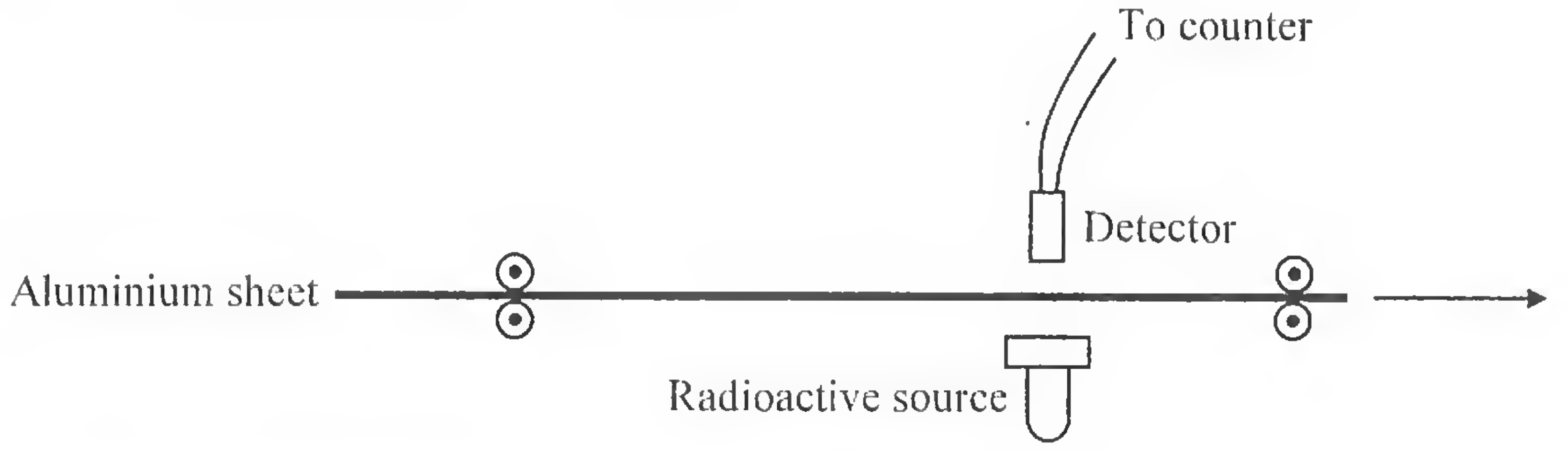
(i) After emitting a β particle, how would the atomic number and mass number of nuclide X be changed ? (2 marks)

(ii) Describe the changes in activity (in disintegrations per second) of a specimen of nuclide X and a specimen of Y after one day. (2 marks)

(iii) Comment on the following statement :

The mass of the specimen containing nuclide X will be reduced by approximately half in 12 hours. (2 marks)

(b) A factory produces aluminium sheets 1 mm in thickness. The thickness of the sheets is monitored by a gauge as shown in the figure below. A β source is used in the gauge.



(i) Explain why α and γ sources are not used in the gauge. (2 marks)

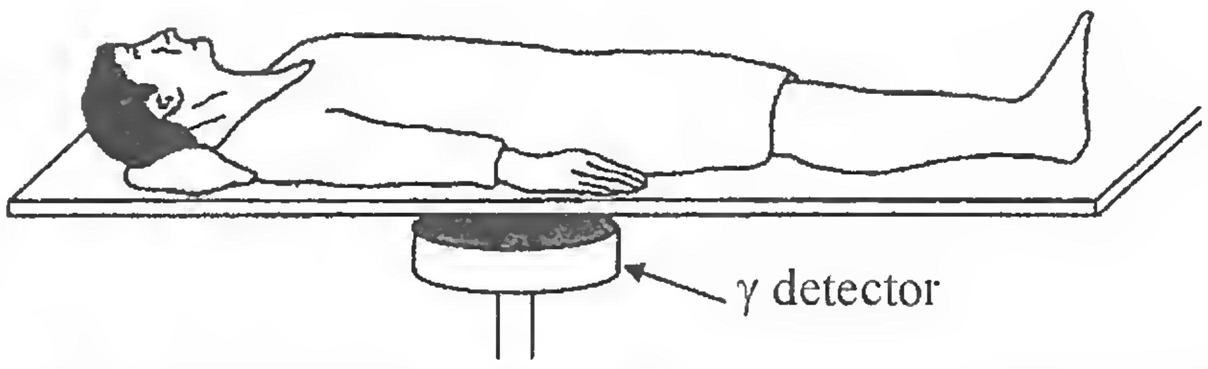
(ii) Which of the nuclides (X or Y) is more suitable to use as the radioactive source ? Explain your answer. (2 marks)

(iii) The count rate recorded should be around 90 counts per second when the thickness of the aluminium sheet is 1 mm. On a certain day when the gauge is operating properly, the following data are recorded :

Time / s	0	10	20	30	40	50	60	70	80	90	100
Recorded count rate / counts per s	90	89	91	90	90	88	66	64	90	89	89

Describe and explain the variation in the readings in the above table. (4 marks)

Q12.
(02)



Iodine-131 ($^{131}_{53}I$) is a radioisotope which decays by emitting a β-particle and γ rays. It is used in hospitals to test the kidneys of patients. During the test, an iodine-131 solution is injected into the bloodstream of a patient. As the blood passes through the kidney, iodine-131 will be absorbed by the kidney and eventually excreted out of the body with urine. If the kidney is not functioning properly, both the absorption and excretion rates of iodine-131 will decrease. A γ-detector is placed near the kidneys of the patient to detect the activity of the radiation coming from the kidneys as shown in the above figure.

(a) Using X to denote the daughter nucleus, write down an equation for the decay of an iodine-131 nucleus. (2 marks)

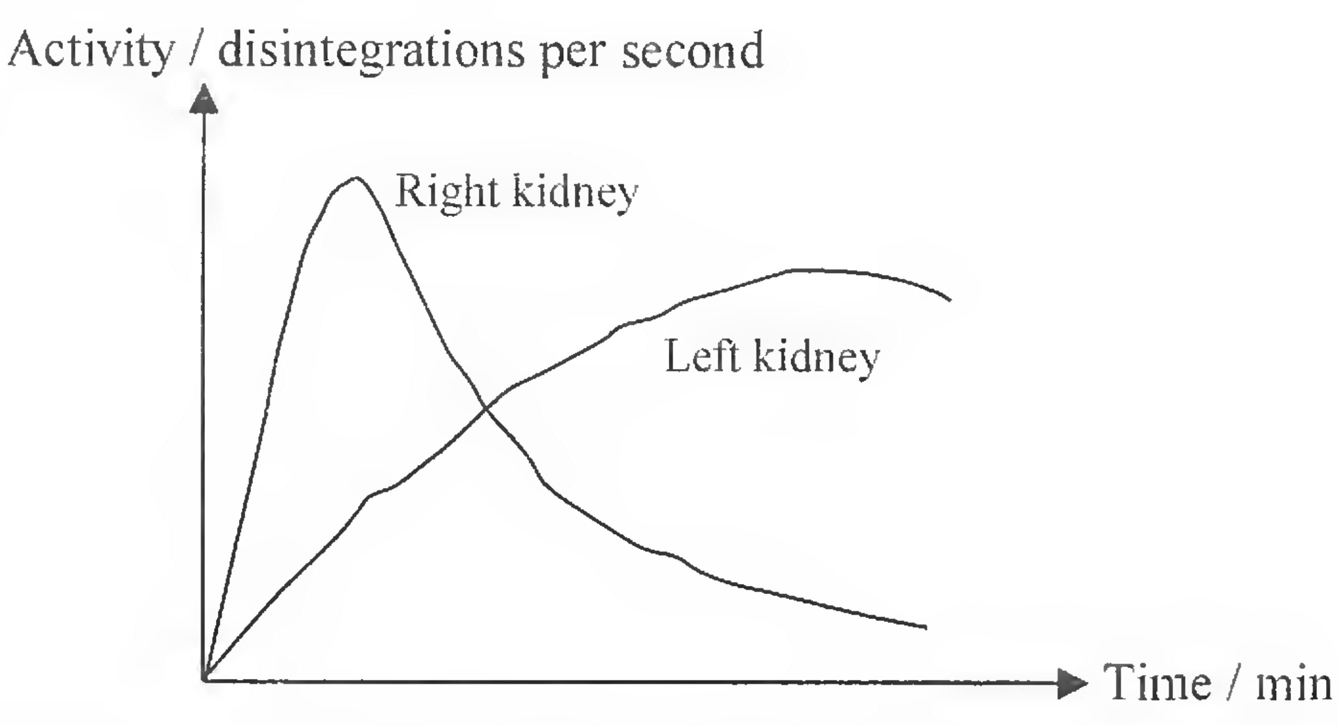
(b) Explain why the β-particles emitted by iodine-131 fail to reach the detector. (1 mark)

(c) The half-life of iodine-131 is 8 days.

(i) State the meaning of 'half-life'. (2 marks)

(ii) For safety purposes, the activity of iodine-131 solution in the test should not exceed 1.5×10^8 disintegrations per second. When an iodine-131 solution is prepared, its activity is 6×10^8 disintegrations per second. How many days after preparation would the solution be suitable for the test ? (2 marks)

(iii)



The above graph shows the variation of the activities of the radiation detected from the right and left kidneys of a patient with time. Which kidney do you think is **not** functioning properly ? Explain your answer. (3 marks)

(iv) Besides iodine-131, technetium-99m is another radioisotope that can be used in the kidney test. Technetium-99m emits γ radiation only and its half-life is 6 hours. Which of these two sources do you think is more preferable for use in the kidney test ? Explain your answer. (4 marks)

Q13.
(04)

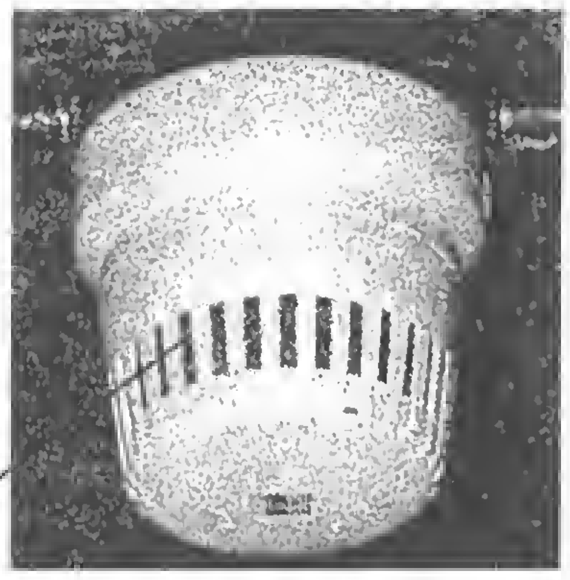


Figure 1

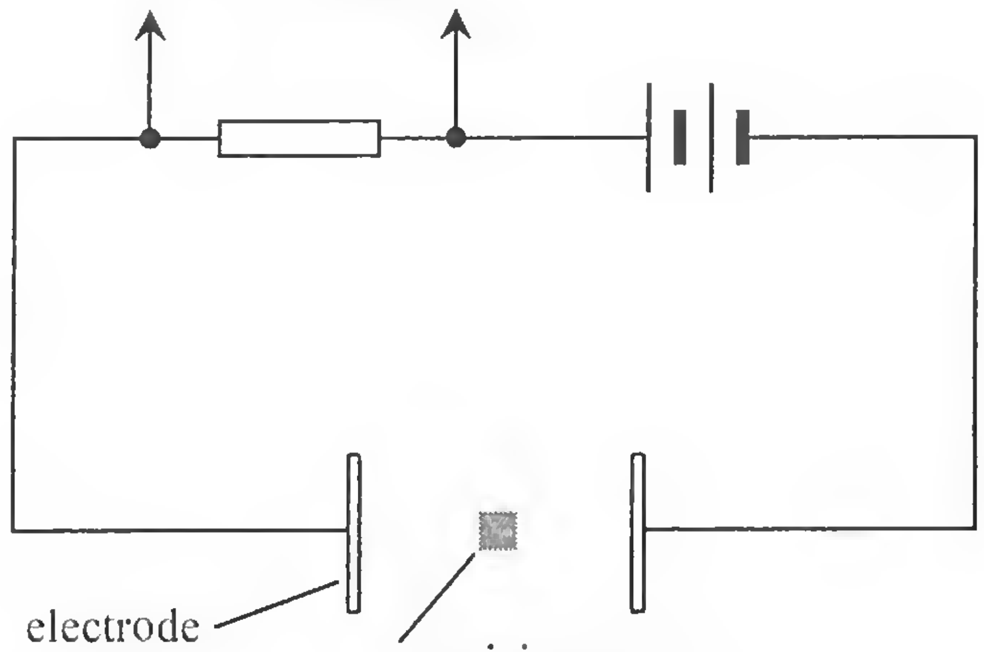


Figure 2

Figure 1 shows a smoke detector. The circuit inside the detector is shown in Figure 2. A small amount of the radioisotope americium-241 (${}^{241}_{95}\mathrm{Am}$) is placed between two electrodes. The two electrodes are connected to a battery and an alarm circuit. The detector has slots in it to allow air flow.

(a) An americium-241 nucleus decays by emitting an α-particle to form a daughter nucleus neptunium (Np), with a half-life of 432 years.

(i) Write down an equation for the decay of an americium-241 nucleus. (2 marks)

____

(ii) Find the number of neutrons in the daughter nucleus. (1 mark)

____

(b) Under normal conditions, a small current flows in the circuit inside the detector. However, when smoke particles enter the detector, the current drops significantly. This triggers the alarm to sound.

(i) Explain why a current flows between the electrodes under normal conditions. (3 marks)

____

____

____

____

(ii) Suggest one possible reason why the current drops when smoke particles enter the detector. (2 marks)

____

____

(c) Explain why it is preferable for the radioactive source used in smoke detectors to have a long half-life. (2 marks)

____

____

(d) Carbon-14 (${}^{14}_{6}\mathrm{C}$) is a radioisotope which decays by emitting β particles and has a half-life of 5700 years. Explain whether this source is suitable for use in smoke detectors or not. (2 marks)

____

____

(e) People are concerned about the biological hazards of radiation. If you are the manufacturer of the above described smoke detector, how would you explain to the public that using the detector will not pose any health hazard ? (2 marks)

____

____

Q14. Read the following passage about Iodine-131 therapy and answer the questions that follow.
(05)

Iodine-131 is a radioisotope which emits β and γ radiation. It can be used for thyroid cancer treatment.

A patient suffering from thyroid cancer will first undergo an operation to have the thyroid gland removed. However, some thyroid tissue may remain in the neck of the patient or may be carried in the blood stream to other parts of the body. Iodine-131 is then used to trace and get rid of the remaining thyroid tissue in the body.

Iodine-131 therapy consists of two stages. In Stage 1, the patient will take a low dose of Iodine-131 to trace the remaining thyroid tissue. A detector is placed near the patient to monitor the activity of the radiation coming from the patient.

In case any remaining thyroid tissue is spotted in Stage 1, the patient will then take a higher dose of Iodine-131 in Stage 2. The iodine will be absorbed by the thyroid tissue and the radiation emitted can kill the cancer cells.

Special hospital rooms are designed for patients who receive Stage 2 of the therapy. The rooms have metallic shielding in the doors and reinforced walls. Inside the rooms, there are plastic covers on the furniture, doors, handles and switches.

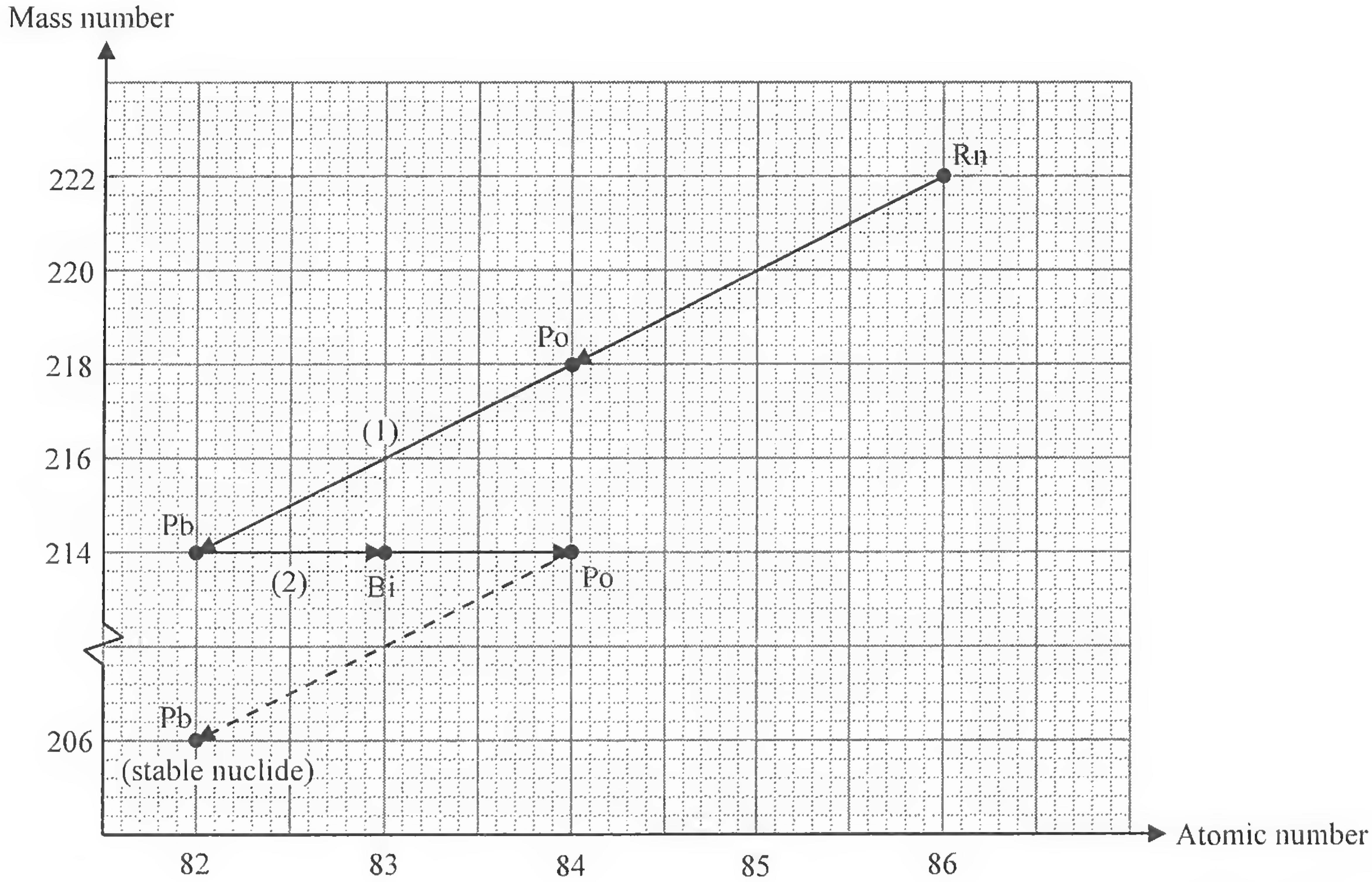
Source : *Iodine-131 Therapy,* The Ohio State University Medical Center, 2003.

(a) Explain why, in Stage 1, β radiation from the patient cannot be detected by the detector. (1 mark)

(b) In Stage 2, which kind of radiation is more effective in killing cancer cells ? Explain your answer. (2 marks)

(c) State one special feature of the hospital rooms designed for patients receiving Stage 2 of the therapy and explain its function. (2 marks)

Q15. (09) Radon-222 (Rn-222) has a half-life of 3.8 days and undergoes a radioactive decay series as shown in the Figure below to become a stable nuclide Lead-206 (Pb-206).



(a) Estimate the mass of undecayed Rn-222 after 15.2 days if its initial mass is 1×10^{-5} g. (2 marks)

(b) State the nuclear radiation emitted in process (1) indicated in the above Figure. (1 mark)

(c) Write down a nuclear equation for process (2) indicated in the above Figure. (2 marks)

(d) Determine the total number of α particles and the total number of β particles emitted in the radioactive decay series from Rn-222 to Pb-206. (4 marks)

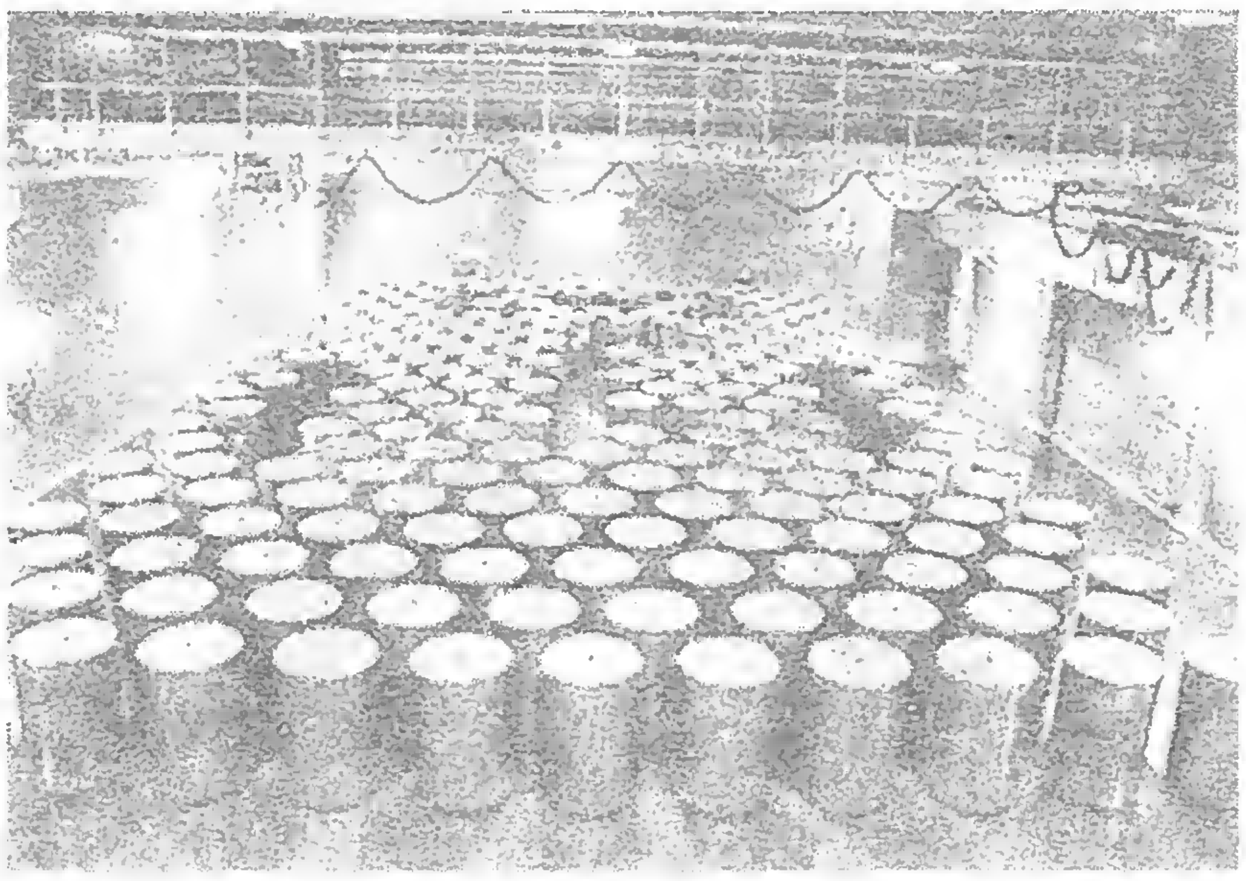
Q16. Read the following passage about low-level radioactive waste and answer the questions that follow.
(10)

Low-level Radioactive Waste

Industrial, medical and educational institutions in Hong Kong generate small amounts of low-level radioactive waste. Such waste produces no detectable heat output and is of low radioactive level. Weakened radiation sources from hospitals and educational institutions are examples of low-level radioactive waste.

For many years, most of the waste had been stored in disused tunnels and hospitals. The Government considers that in the long run the low-level radioactive waste should be stored in a purpose-built facility. After about two years of construction, the Low-level Radioactive Waste Storage Facility (the Facility) (see the Figure below) at Siu A Chau, an uninhabited island to the southwest of Lantau Island, was successfully commissioned and began its operation in July 2005. It comprises a shielded waste storage vault, a fully equipped laboratory. an automatic control room, an advanced wastewater treatment plant and specially designed waste reception and processing area. The radiation levels inside and outside the Facility are continuously monitored to ensure safe operation.

The Low-level Radioactive Waste Storage Facility at Siu A Chau - Storage Vault



(a) State **one** characteristic of low-level radioactive waste. (1 mark)

(b) Explain why Siu A Chau is suitable for the storage of low-level radioactive waste. (1 mark)

(c) Suggest an instrument to monitor the radiation levels inside and outside the Facility. (1 mark)

(d) In hospitals, radioactive sources are used as tracers. The radioactive source is injected into a patient's body and the radiation level is monitored with detectors outside the body. Explain why γ source is suitable for using as tracers. (2 marks)

Q17. (10) Carbon-14 dating can be used to identify the age of some objects. Living organisms contain a constant proportion of carbon-14. After an organism dies, the amount of carbon-14 in it decreases due to decays. We can estimate the age of an object by measuring the activity of carbon it contains.

(a) Carbon-14 undergoes decay as shown in the following nuclear equation, where D denotes the daughter nucleus.

$$^{14}_{6}\text{C} \rightarrow {}^{y}_{x}\text{D} + \beta$$

Find the values of x and y. (2 marks)

(b) In a piece of wood found, the activity of 10 g of carbon is 35 disintegrations per minute. It is known that the activity due to 10 g of carbon in a living plant is 140 disintegrations per minute. Estimate the age of this piece of wood. Given that the half-life of carbon-14 is 5700 years. (3 marks)

Q18. (11) It is known that plutonium-238 ($^{238}_{94}\text{Pu}$) decays by emitting one α particle.

(a) Write a nuclear equation for the decay of plutonium-238. Use the symbol Y as the daughter nucleus. (2 marks)

(b) A sample of plutonium-238 is put in a cloud chamber. Some tracks are seen.

(i) Describe the tracks that are seen. (1 mark)

(ii) No tracks can be seen when the sample is covered by a piece of paper. Explain. (2 marks)

(c) Plutonium-238 can be used in heater units in spacecrafts for outer space missions. It is known that the power of the heater unit is directly proportional to the activity of plutonium-238 contained. Each heater unit has a power of 2 W when it is newly manufactured. How long can a newly manufactured heater unit last if the minimum power output required is 0.25 W ?

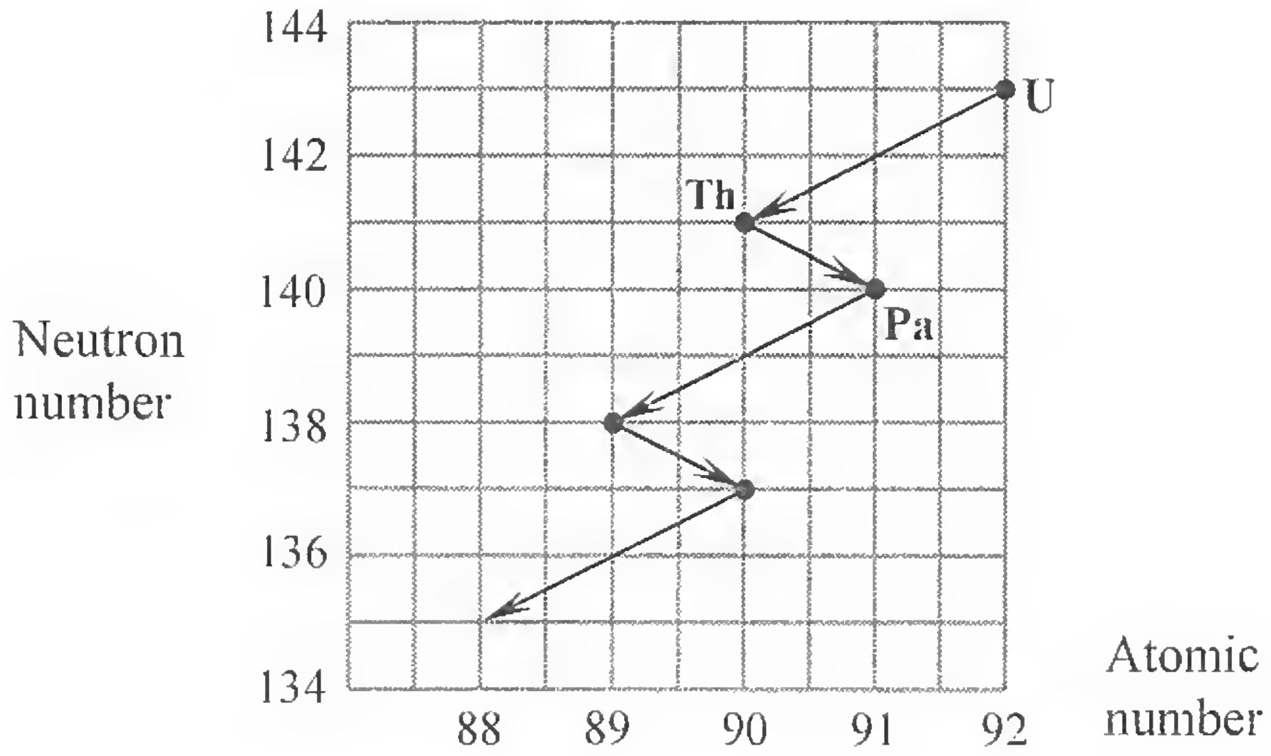
Given : half-life of plutonium-238 = 87.7 years (3 marks)

Part C :

The following questions marked with [ ] are the past HKAL questions.

The number inside the brackets represents the year of the examination.

Q19. The figure below shows the decay series for $^{235}_{92}\text{U}$.
[93]



(a) Name the particles emitted when

(i) Uranium (U) decays to Thorium (Th); and (1 mark)

(ii) Thorium (Th) decays to Protactinium (Pa). (1 mark)

(b) Given that the half-life of $^{235}_{92}\text{U}$ is 7.1×10^8 years, what would be the percentage of $^{235}_{92}\text{U}$ left after a period of 10^8 years ? (3 marks)

Q20. Carbon-14 dating is used to determine the age of archaeological sample by measuring its activity due to the carbon-14 remaining in it.
[09]

(Given : mass of one mole of carbon-12 = 12.0 g and half-life of carbon-14 $t_{1/2}$ = 5730 years)

(a) (i) Calculate the decay constant k, in s^{-1}, of carbon-14. (2 marks)

(ii) It is known that the relative abundance of carbon-14 in living things is that there is only one carbon-14 atom for every 7.2×10^{11} atoms of carbon-12. Calculate the activity for 1 g of carbon in living things. (3 marks)

Q20. (b) (i) Explain the origin of carbon-14 in the atmosphere and why the abundance of carbon-14 in living things, such as plants, remains more or less constant. (3 marks)

(ii) After corrected for background radiation, an archaeologist measured an activity of 20 disintegrations per minute from 10 g of carbon in a piece of bone. Use the result in (a) to estimate the age of the bone. (3 marks)

Q1. (a) $k = \dfrac{\ln 2}{5730 \times 3.16 \times 10^7} = 3.83 \times 10^{-12}\ s^{-1}$ [1]

By $A = kN$

$\therefore\ (0.2) = (3.83 \times 10^{-12})\, N$ [1]

$\therefore\ N = 5.22 \times 10^{10}$ [1]

(b) $N_o = (1 \times 10^{23}) \times (1.3 \times 10^{-12}) = 1.3 \times 10^{11}$ [1]

(c) $N = N_o\, e^{-kt}$

$(5.22 \times 10^{10}) = (1.3 \times 10^{11})\ e^{-(3.83 \times 10^{-12})t}$ [1]

$\therefore\ t = 2.38 \times 10^{11}\ s = 7540$ years < accept 7500 to 7600 years > [1]

Q2. (a) (i) β should be used. [2]

(ii) α is not used because it is totally absorbed by the aluminium sheet [2]

γ is not used because the count rate would not be affected significantly by the aluminium sheet. [1]

(b) Any **TWO** of the following : [2]

- radiotherapy
- estimate the age of archaeological samples
- medical tracer
- sterilization
- leakage test of underground oil pipes
- smoke detection

[Note : Thickness gauge is NOT acceptable since it is the application in part (a).]

Q3. (a) (i) Atomic number of resulting nucleus $= 92 - 4 \times 2 + 2$ [2]

$= 86$ [1]

Mass number of resulting nucleus $= 238 - 4 \times 4$ [2]

$= 222$ [1]

(ii) β and γ [2]

(iii) Count-rate decreases [1]

since only background radiation can be detected at point B [1]

(b) There are 2 half-lives in 20 hours [1]

Original activities in 10 cm³ of blood $= 2 \times 2 \times 2$ [1]

$= 8$ [1]

Volume of blood $= 10 \times \dfrac{4400}{8}$ [1]

$= 5500\ cm^3$ [1]

Q3. (c) Mass number $= 224 - 4 = 220$ [1]

Atomic number $= 88 - 2 = 86$ [1]

Q4. (a) (i) mass number of $\alpha = 4$ [1]

(ii) mass number of $\beta = 0$ [1]

(iii) mass number of neutron $= 1$ [1]

(b) $^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}X + {}^{4}_{2}\alpha$ [3]

(c) atomic number $= 91 - 2 + 1 = 90$ [1]

mass number $= 234 - 4 = 230$ [1]

(d) (i) $A \longrightarrow B$: α particle [1]

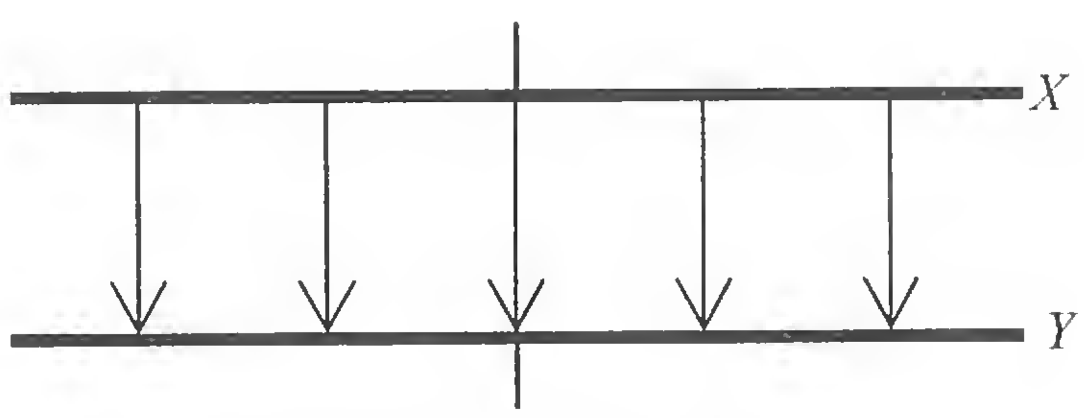
$B \longrightarrow C$: β particle [1]

$C \longrightarrow D$: α particle [1]

$D \longrightarrow E$: α particle [1]

(ii) Mass number of $C = 141 + 92 = 233$ [1]

Q5. (a) (i)



< Direction of electric field lines is downwards > [1]

< The electric field lines are parallel and evenly spaced > [1]

(ii) Air molecules are ionized by α particles. [1]

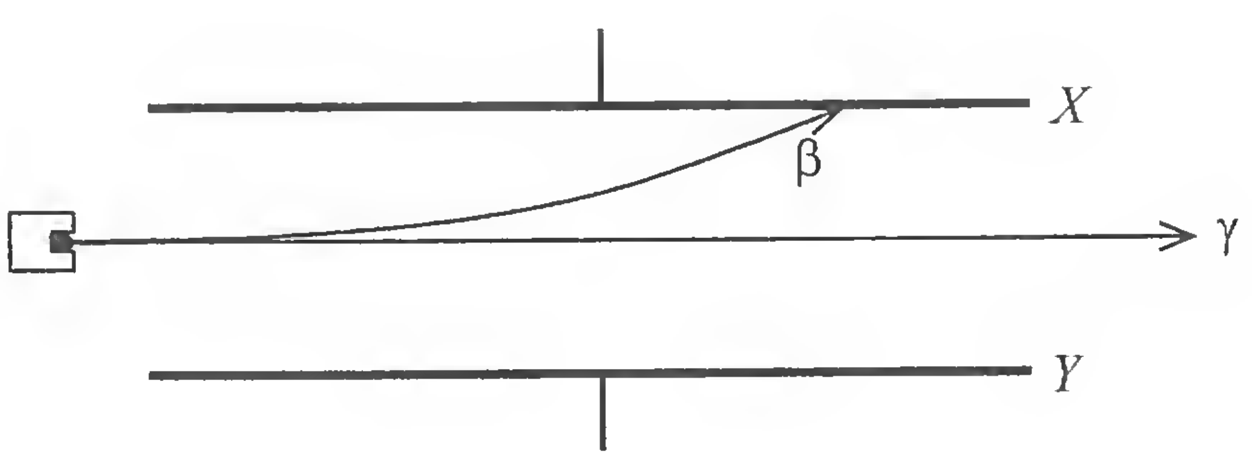
The ions then move to the metal plates to conduct a current. [1]

(iii) The ammeter reading decreases ; (OR becomes zero) [1]

since the ionizing power of γ radiation is very weak. [1]

(iv) (1) $^{234}_{91}\text{Pa} \longrightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\beta + \gamma$ [1]

(2)



< β is deflected upwards > [1]

< γ is not deflected > [1]

Q5. (b) (i) A γ source should be used. [1]

Since the penetrating power of γ is high enough to reach the ground. [1]

(ii) The source with half life 10 hours should be used. [1]

Reason : (Any **ONE** of the following) [2]

- ✲ It gives less pollution to the environment as its activity disappears quickly
- ✲ It causes less harmful effect to the environment as its activity disappears quickly

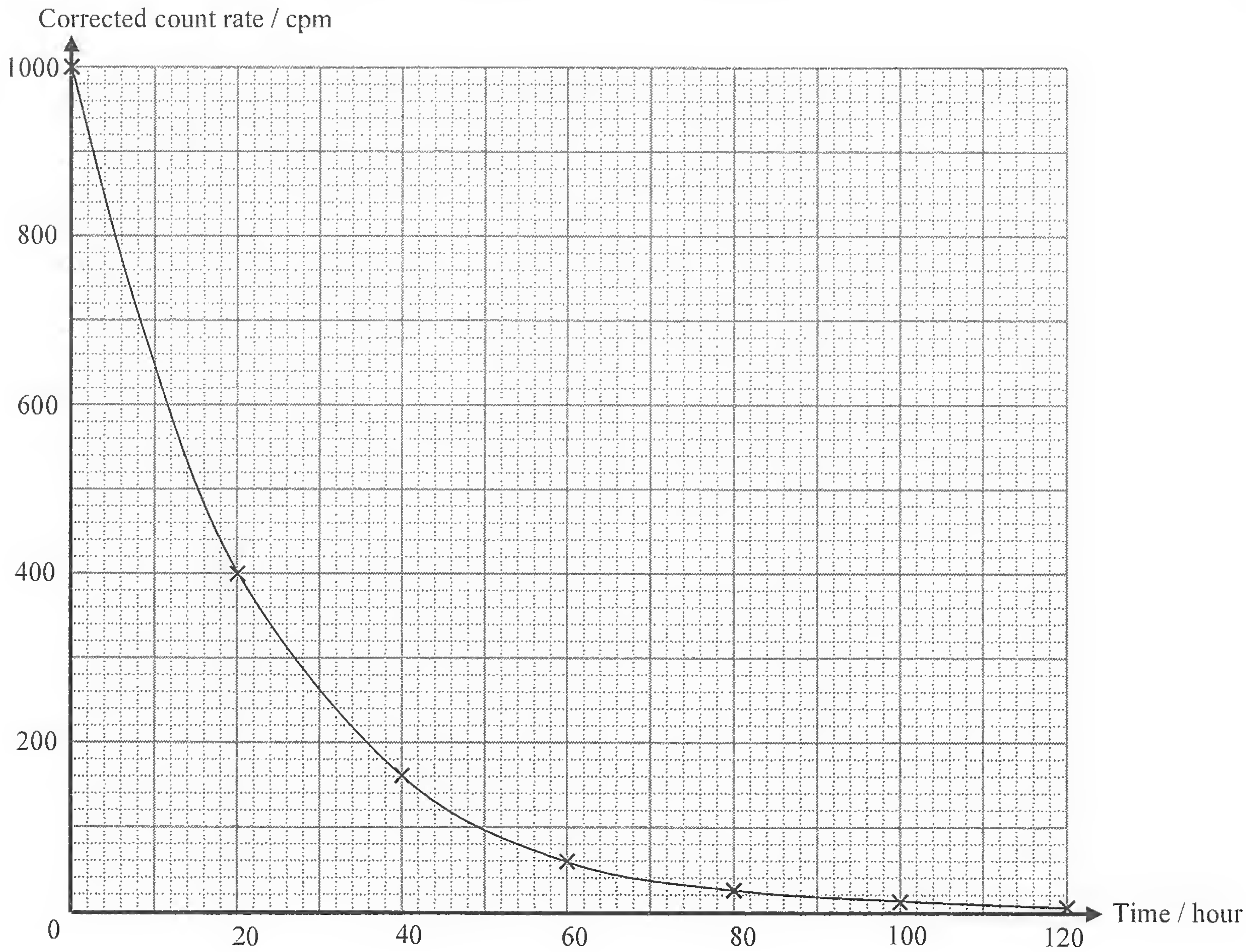
Q6. (a) Any **TWO** of the following : [2]

- ✲ Cosmic radiation from the space
- ✲ Radiation from the rocks
- ✲ Radiation from air
- ✲ Radiation from food

(b)

Time / hour	0	20	40	60	80	100	120
Corrected count rate / cpm	1000	398	159	61	25	10	4

[1]



< Two axes labelled correctly > [1]

< Suitable scales chosen > [1]

< At least 5 points plotted correctly > [1]

< Smooth curve drawn > [1]

Q6. (b) Half-life = 15 hours   < 14 – 16 hours is acceptable > [1]

(c) Yes, it is suitable [1]

The half-life is long enough for the doctor to diagnose the patient. [1]

The half-life is short enough to cause less harmful effect on the patient. [1]

OR

The half-life is not too short [1]

and not too long. [1]

Q7. (a) (i) α particle [1]

(ii) β particle [1]

(b) *A* and *D* are isotopes of each other. (**OR** *B* and *E*) [1]

(c) (i) Mass number of A = 142 + 90 = 232 [1]

Mass number of X = 126 + 82 = 208 [1]

(ii) Total number of α particles emitted $= \dfrac{232 - 208}{4}$ [1]

$= 6$ [1]

(d) γ emission does not change the atomic number and mass number of the nuclide. [2]

(e) (i) β and γ radiation can reach the counter because their ranges in air are longer than 20 cm. [2]

(ii) A corrected count rate is equal to the recorded count rate minus the background count rate. [2]

(iii) The readings differ due to the random nature of radiation. [2]

Q8. (a) A β source should be used. [1]

An α source is not suitable because α particles cannot pass through the container. [1]

A γ source is not suitable because γ radiation is too penetrating. [1]

(**OR** cannot be absorbed by the container)

(b) A GM tube (**OR** Geiger Muller tube) (**OR** GM counter) can be used. [1]

(c) If a bottle not filled up to the required level passes the source,

the counter will record a much higher reading than that when an acceptable bottle passes the source, [2]

since the β radiation does not pass through the detergent and hence is not absorbed. [1]

Q10. (a) $^{24}_{11}\text{Na} \longrightarrow {}^{24}_{12}\text{Mg} + {}^{0}_{-1}\beta$ [2]

(b) The GM tube is held close from the source and its reading is noted. [1]

Insert a piece of paper between the GM tube and the source. [1]

The count rate would remain unaffected. This shows that the source does not emit α particles. [1]

Insert the aluminium sheet between the tube and the source. The count rate would drop significantly. [1]

This shows that the source emits β particles.

(c) (i) Number of half-lives elapsed $= \dfrac{45}{15} = 3$ [1]

(ii) Initial activity of 6 cm^3 of blood $= 5 \times 2^3 = 40$ [1]

$\therefore \quad \dfrac{V}{6} = \dfrac{32 \times 10^3}{40}$ [1]

$\therefore \quad V = 4800 \text{ cm}^3$ [1]

(c) (iii) Any **TWO** of the following : [2]

- ✲ The half-life is long enough for medical diagnosis.
- ✲ The half-life is short enough to reduce the harmful effect to the human body.
- ✲ The daughter nuclei Mg is stable and has no harmful effect.
  (**OR** Sodium and magnesium have no harmful chemical effects on human body.)

(d) (i) Any **ONE** of the followings : [1]

- ✲ Radiotherapy
- ✲ Medical tracer
- ✲ Sterilization of medical equipment

(ii) Any **ONE** of the followings : [1]

- ✲ Thickness gauge
- ✲ Food preservation (Sterilization of beef)
- ✲ Leakage detection
- ✲ Radioactive lightning conductor
- ✲ Smoke detector

Q11. (a) (i) The atomic number increases by one. [1]

The mass number remains unchanged. [1]

(ii) The activity of specimen X will fall to a quarter of its original value. [1]

The activity of specimen Y will remain approximately unchanged. [1]

(iii) As the mass of β particles emitted is very small, [1]

the mass of the specimen would almost remain unchanged after 12 hours. [1]

Q11. (b) (i) α source is not used because the penetrating power of α particles is too low. [1]

γ source is not used because the penetrating power of γ radiation is too high. [1]

(ii) Nuclide Y is more suitable. [1]

As nuclide Y has a longer half-life, its activity remains stable over a longer period of time. [1]

(iii) The reading remains steady from $t = 0$ to 50 s and from $t = 80$ to 100 s. [1]

The small variation within this period is due to the random nature of radioactive decay. [1]

The reading drops significantly from $t = 60$ to 70 s. [1]

The aluminium sheet in this period is thicker than the normal value. [1]

Q12. (a) $^{131}_{53}\text{I} \longrightarrow {}^{131}_{54}\text{X} + {}^{0}_{-1}\beta$ **OR** $^{131}_{53}\text{I} \longrightarrow {}^{131}_{54}\text{X} + {}^{0}_{-1}\beta + \gamma$ [2]

(b) The β particles fail to pass through the human body. [1]

<u>OR</u>

The β particles are absorbed by the human body. [1]

(c) (i) The half-life is the time taken for the activity of the source to drop to half of its initial value. [2]

(ii) No. of half-life = 2 [1]

The solution is suitable after $2 \times 8 = 16$ days [1]

(iii) The left kidney is not functioning properly [1]

since the activity in the left kidney increases at a lower rate. [2]

(iv) Technetium-99*m* is more preferable than iodine-131 for use in the test. [1]

Since technetium-99*m* has a shorter half-life [1]

and does not emit β particles, [1]

so it causes less harmful effect to the patient. [1]

Q13. (a) (i) $^{241}_{95}\text{Am} \longrightarrow {}^{237}_{93}\text{Np} + {}^{4}_{2}\alpha$ [2]

(ii) Number of neutrons = $237 - 93 = 144$ [1]

(b) (i) The α-particles will ionize the air to give ions. [2]

The ions the move to the electrodes to give a current. [1]

(ii) The smoke particles block the movement of the charged particles. [1]

As a result, fewer ions reach the electrodes, so the current drops. [1]

Q13. (c) The activity of the source will remain stable for a long period of time. (**OR** decay very slowly) [1]
So the detector can be used for a longer timer. (**OR** The source needs not be replaced frequently.) [1]

(d) As β particles have a weaker ionizing power, [1]
the current flowing between the electrodes will be extremely small. [1]
So Carbon-14 is not suitable.

(e) Any **ONE** of the following : [2]

- The radiation dose from the smoke detector is very small.
- The radiation from the smoke detector is much less than the background radiation.
- The source used in the smoke detector is a very weak source.
- α-particles have a very short range in air.

Q14. (a) The penetrating power of β radiation is too low. [1]
OR
β radiation cannot penetrate through human body. [1]

(b) β radiation is more effective in killing cancer cells. [1]
Since the ionizing power of β is higher than that of γ radiation. [1]

(c) The rooms have metallic shielding in the doors and walls. [1]
They can prevent radiation from leaking out of the rooms. [1]
OR
Inside the rooms, there are plastic covers on the furniture, doors, handles and switches. [1]
This prevents other persons using the room from being contaminated. [1]

Q15. (a) Number of half-lives $= \dfrac{15.2}{3.8} = 4$ [1]

Mass of Rn-222 left $= 1 \times 10^{-5} \times (\frac{1}{2})^4 = 6.25 \times 10^{-7}$ g [1]

(b) α [1]

(c) ${}^{214}_{82}\text{Pb} \rightarrow {}^{214}_{83}\text{Bi} + {}^{0}_{-1}\beta$ [2]

(d) Let a and b be the number of α particles and β particles respectively.
$222 - 206 = 4a$ [1]
$a = 4$ [1]
$86 - 82 = 4 \times 2 - b$ [1]
$b = 4$ [1]

Q16. (a) It produces no detectable heat output. [1]

OR

It has a low radioactive level. [1]

(b) It is because it is an uninhabited place. [1]

(c) GM counter (**OR** GM tube) [1]

OR

photographic film [1]

(d) It has weak ionizing power [1]

and causes less harmful effect to the human body. [1]

OR

It has strong penetrating power [1]

and can pass through the body to be detected outside the body. [1]

Q17. (a) $x = 7$ [1]

$y = 14$ [1]

(b) $35 = 140\left(\frac{1}{2}\right)^n$ **OR** $140 \rightarrow 70 \rightarrow 35$ [1]

$\therefore\ n = 2$ [1]

The age of the wood $= 2 \times 5700 = 11400$ years [1]

Q18. (a) ${}^{238}_{94}\mathrm{Pu} \rightarrow {}^{234}_{92}\mathrm{Y} + {}^{4}_{2}\mathrm{He}$ (OR ${}^{4}_{2}\alpha$) [2]

(b) (i) The tracks are straight. [1]

OR

The tracks are thick. [1]

(ii) As α radiation has weak penetrating power, [1]

they are stopped by the paper. [1]

(c) $2\ \mathrm{W} \rightarrow 1\ \mathrm{W} \rightarrow 0.5\ \mathrm{W} \rightarrow 0.25\ \mathrm{W}$ [1]

OR

$\frac{0.25}{2} = \left(\frac{1}{2}\right)^n \quad \therefore\ n = 3$ [1]

Hence, the heater can last 3 half-lives. [1]

Time $= 3 \times 87.7 = 263.1$ years < accept 263 years > [1]

Q19. (a) (i) α particle [1]

(ii) β particle [1]

(b) $k = \dfrac{\ln 2}{7.1\times10^{8}} = 9.76\times10^{-10}$ year^{-1} [1]

$N = N_o\, e^{-kt} = N_o\, e^{-(9.76\times10^{-10})\times(10^{8})} = 0.907\ N_o$ [1]

$\therefore$ percentage left = 90.7% [1]

OR

$N = N_o\left(\dfrac{1}{2}\right)^{t/t_{1/2}}$ [1]

$N = N_o\left(\dfrac{1}{2}\right)^{(10^{8})/(7.1\times10^{8})} = 0.907\, N_o$ [1]

$\therefore$ percentage left = 90.7% [1]

Q20. (a) (i) $k = \dfrac{\ln 2}{t_{1/2}} = \dfrac{\ln 2}{(5730\times365\times24\times3600)}$ [1]

$= 3.84\times10^{-12}\ \text{s}^{-1}$ [1]

(ii) Number of carbon-14 atoms in 1 g of carbon :

$N = \dfrac{1}{12}\times6.02\times10^{23}\times\dfrac{1}{7.2\times10^{11}} = 6.97\times10^{10}$ [1]

$A = kN = (3.84\times10^{-12})\times(6.97\times10^{10})$ [1]

$= 0.268$ Bq < accept 0.267 Bq > [1]

(b) (i) Carbon-14 is formed when neutrons produced by cosmic rays collide with nitrogen.

$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{14}_{6}C + ^{1}_{1}p$ [1]

Carbon-14 forms radioactive carbon dioxide and is taken up by plants for photosynthesis (**OR** Carbon-14 is taken up by animals through eating). [1]

This exchange maintains the same abundance inside a living thing until it dies. [1]

(ii) Activity of the bone per gram : $A = \dfrac{20}{60}\times\dfrac{1}{10} = 0.0333$ Bq [1]

By $A = A_0\, e^{-kt}$ $\therefore$ $(0.0333) = (0.268)\, e^{-(3.84\times10^{-12})t}$ [1]

$\therefore$ $t = 5.43\times10^{11}$ s = 17200 years [1]

OR

By $(0.0333) = (0.268)\,(\frac{1}{2})^{n}$ $\therefore$ $n = 3.01$ [1]

Age = 3.01 × 5730 = 17200 years [1]

GCE AL Physics (Edexel) course C.W.Sham

Unit 1 : Physics on the go

1.1 Mechanics

1.2 Material

Unit 2 : Physics at work

2.1 Waves

2.2 DC Electricity

2.3 Nature of light

Unit 4 : Physics on the move

4.1 Further Mechanics

4.2 Electric Field

4.3 Magnetic field

4.4 Particle Physics

Unit 5 : Physics from creation to collapse

5.1 Thermal energy

5.2 Nuclear energy

5.3 Oscillation

5.4 Astrophysics and cosmology

✲ 沈sir錄了一套英國 GCE AL 的課程，放在 VIP，供有需要的同學報讀。

✲ 這課程是專為有意往外國升讀大學的同學而設。

✲ 全套課程只有四個單元(unit)。

✲ 每單元只有四堂，每堂約一小時四十五分至二小時。

✲ 讀完單元一 (unit 1)及單元二 (unit 2)，相等於完成英國中六的物理課程。

✲ 讀完單元四 (unit 4)及單元五 (unit 5)，相等於完成英國中七的物理課程。

✲ 筆記全英文，上課語言是廣東話。

✲ 每一單元的考試可以獨立報考和重考，直至獲得滿意成績。

✲ 單元三 (unit 3)是考核單元一及二的實驗卷。

✲ 單元六 (unit 6)是考核單元四及五的實驗卷。

✲ 考獲單元一至三的合格成績，報讀美國四年制大學，等同中六 AS 程度。

✲ 考獲單元一至六的合格成績，報讀英國三年制大學，等同中七 AL 程度。

CW Sham

香港大學榮譽理學士兼持有香港大學教育文憑

34年經驗　完美筆記演繹

實力超班 · 名校熱捧

- 香港大學榮譽理學士兼持有香港大學教育文憑
- 34年任教中學會考(HKCEE)、高級程度會考(HKAL)及中學文憑試(HKDSE)物理科經驗
- 沈Sir多年的教學經驗，深受各區名校理科生的追捧，成為物理科摘星之選

物理權威 · 亦師亦友

- 沈Sir一直與學生保持朋友關係，十分親切，透過不同貼近學生的途徑，教授物理的知識及攻略
- FACE 學園物理科主講嘉賓

經驗取勝 · 轉弱為強

- 沈Sir歷任各級公開考試的閱卷員。物理科每張試卷每部份都曾親身評核過，深明學生取分之道，亦深知考生弱點
- 所有筆記是由沈sir以三十四年教學及十多年考評機構的工作經驗而編寫，概括新高中課程的考試範圍
- 每課都附有過往三十四年的公開試相關題目作練習，並有詳細答案和解釋

物理知識融會貫通 · 考試上陣輕鬆

- 教學方式由淺入深，並附有很多生活化的例子，使同學能夠把物理學習和日常生活聯成一起，增加學習興趣
- 考試答題技巧，評分準則都會在課堂中詳細講解
- 沈Sir擅長以圖表、圖解深入淺出地闡釋艱深的物理概念，更設計了一套完整習作及詳解，涵蓋考試要點
- 堂上精闢的講解，令學生茅塞頓開，學習樂在其中，對考試充滿信心

課程查詢熱線: 2474 4267

Email: cwsham@beacon.com.hk

cwsham901